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# FSCBG MODEL COMPARISONS WITH THE 1980 WITHLACOOCHEE STATE SEED ORCHARD SPRAY TRIALS - CANOPY DEPOSITION AND SPRAY DRIFT

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## Foreword

The Withlacoochee seed orchard project provided an opportunity to demonstrate the feasibility of using aircraft to dispense insecticides to control seed and cone insects. The project also provided the opportunity to evaluate the USDA Forest Service Cramer-Barry-Grim (FSCBG) and Agricultural Dispersal (AGDISP) models. Results of this multiple objective project have been published previously. With the enhancement of FSCBG over the 15 years since the Withlacoochee project, it was decided to revisit the data set and compare performance of the enhanced FSCBG model predictions to observed field data.

In 1979, Harold Flake, entomologist-in-charge of the USDA Forest Service, Forest Insect and Disease Management field office in Asheville, NC, had need for improved technology to reduce loss of pine seed from seed and cone insects. Existing methods of applying chemical insecticides by ground sprayers were not reducing crop losses from insects. Federal, state and private orchards in some cases were losing up to 90% of their crop annually to single and/or multiple complexes of insects. There was a shortage of seed from high value seed trees to support the Southern reforestation and plantation forestry program. Some seed values were estimated at $900 to $1000 per pound.

Harold Flake approached me with the idea of demonstrating aerial application to southern seed orchards given its potential as a more efficient and efficacious method of controlling seed and cone insects. The State of Florida offered their Withlacoochee seed orchard for the demonstration and we commenced with a series of aerial spray tests using a simulated insecticide spray. The project clearly demonstrated the feasibility of using aircraft to apply aerial sprays and to achieve aerial spray coverage throughout the canopy. Follow-on tests at other orchards demonstrated biological effectiveness. Orchard managers, convinced by these demonstrations, adopted aerial application as a primary means of applying insecticides to seed orchards. Its safety, economics, efficiency, and efficacy were demonstrated and accepted by the practitioner.

Thanks to Harold Flake for his vision and initiative in bringing forth this technology, to Larry Barber for his energies, motivation and scientific skills in coordinating the field activities, and to the other USDA Forest Service entomologists in Pineville and Asheville, NC who supported this technology transfer effort. Without Gary DeBarr's renowned research on the biology and life history of seed and cone insects and his field work, the control program would remain in its infancy. Bob Ekblad, engineer with the Missoula Technology Development Center provided critical engineering support to the project at Withlacoochee and as project manager of AGDISP. Hoover Lambert, a proud member of Cherokee Nation's eastern band who dedicated his career to the USDA Forest Service, is remembered for his field leadership in forest health protection and for his outstanding contributions in supporting the Withlacoochee project. And thanks to all of the others - Federal, State and private cooperators - for sharing their resources and knowledge in advancing management of seed and cone insects.

John W. Barry
Davis, CA
February 6, 1996

# Executive Summary

This paper evaluates deposition of an aerial spray into two separate species of pine in a seed orchard. Twelve field trials were conducted at Withlacoochee State Seed Orchard, Brooksville, FL, in 1980. Seven trials involved a fixed-wing aircraft and five trials involved a helicopter. Both aircraft used conventional hydraulic nozzles and boom. Ground deposition data were collected on Kromekote and Mylar cards, and canopy deposition data were collected on Kromekote-wrapped beverage can samplers placed throughout the two pine canopies.

USDA Forest Service Cramer-Barry-Grim (FSCBG) aerial spray computer model simulations of ground deposition are presented for the field trials, and are compared to field test data. Predicted and observed droplet size data are also compared. Previous studies of the Withlacoochee data set have used earlier versions of FSCBG; results from these studies are compared to results of the current study. The enhancements made to FSCBG in the fifteen years since the Withlacoochee trials were first studied have significantly improved its prediction of deposition on the ground and in the orchard canopy.

Canopy modeling is presented for each tree type. Predicted deposition at specific locations in the canopy is compared to field test data from the beverage can tops, as well as from elements of foliage in both types of pine canopy. Drift deposition data over open terrain are also evaluated.

FSCBG is shown to model drop deposition near the top of the canopy very well, with very good correlation of average predicted deposition to the average field test data (least squares slope = 0.87). Average correlation to spray mass of observed and predicted ground deposition under the canopy is $R^2 = 0.57$. Drop density deposition to 80 meters downwind is also predicted well.

# Table of Contents

# 1. Introduction

The field trials conducted in 1980 at Withlacoochee State Seed Orchard in Brooksville, FL, provide both ground and canopy deposition data of aerial sprays applied by both fixed-wing and helicopter platforms. Two types of tree were planted in the treatment area: slash pine and Ocala sand pine. Beverage can samplers were placed throughout sample trees to collect canopy deposition data for both types of pine canopies. Beverage can samplers were also strung between sample trees in lines 0.15 meters below the canopy top, perpendicular to the aircraft flight path. Kromekote cards were used to collect ground deposition data. The trials were conducted with a Stearman biplane and a Hughes 500C helicopter. Both aircraft applied a tank mix of water, salt tracer, and Rhodamine dye with conventional hydraulic nozzle spray systems.

The purpose of the project reported herein is to simulate drop deposition within the canopy, and to simulate mass deposition data at ground level, both under the canopy and in the open (for downwind drift). The USDA Forest Service Cramer-Barry-Grim (FSCBG) aerial spray model (Teske et al. 1993b) is used to model the orchard canopy and predict the levels of deposition expected just below the canopy top and in the tree crowns, as well as to predict ground deposition. Both types of pine canopy in the treatment area are modeled. Predicted levels of deposition are then compared to field data from the tops of the can samplers and to ground card data.

The USDA Forest Service in cooperation with the U.S. Army developed the FSCBG aerial spray model and its near-wake Agricultural Dispersal (AGDISP) model (Bilanin et al. 1989). FSCBG predicts the transport and behavior of sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP near-wake representation solves a Lagrangian system of equations for the position and position variance of material released from each nozzle on the spray aircraft. The FSCBG far-wake representation begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover canopy and ground deposition.

Technical aspects of the FSCBG model are discussed in Teske et al. (1993b). Previous comparisons with data are numerous and include a series of validation studies accomplished since 1993 (MacNichol and Teske 1993a, 1993b, 1994a, 1994b, 1995; MacNichol 1996). Studies which have used FSCBG canopy modeling capabilities for coniferous canopies include: MacNichol and Teske (1994b), Douglas fir; Rafferty et al. (1982), Southern pine; and Teske et al. (1991), Douglas fir. Several other studies have evaluated oak and broadleaf canopies: Anderson et al. (1992), eastern oak; Rafferty and Grim (1992), Gambel oak; Teske, Barry and Rafferty (1994), Gambel oak; Teske et al., (1993a), broadleaf canopies; and MacNichol (1996), almond trees.

# 2. Field Trials Summary

## 2.1 Scope of the Field Trials

In early 1980 a set of spray trials were conducted at Withlacoochee State Seed Orchard, Brooksville, FL (Barry et al., 1982) as a cooperative project between the USDA Forest Service and Florida Forest Service. The trials took place in February. The objectives of the field test were to compare and evaluate deposition on seed orchard pines using aerial and ground spraying, and to exercise an early version of FSCBG. The Withlacoochee spray trials are described in detail by Rafferty et al. (1982) and Barry et al. (1982).

There were eighteen trials conducted, six with ground sprayers and twelve with aerial spraying. Seven of the aerial trials were conducted with a fixed-wing aircraft equipped with a D6-46 hydraulic nozzle spray system, and five of the aerial trials were conducted with a helicopter equipped with a D2-45 hydraulic nozzle spray system. The scope of the Withlacoochee spray trials is shown in Table 1. Not all ground samplers, tree samplers, and top-of-canopy samplers were used in all of the trials; thus, only eight trials are modeled with FSCBG (trials 2, 3, 5, 6, 7, 10, 11, and 13).

A schematic of the orchard is shown in Figure 1. An area of approximately 400 meters by 800 meters, containing equal numbers of slash pine and Ocala sand pine, was selected as the test site. The aircraft flew in south-to-north, north-to-south swaths over portions of the test area, as indicated in Table 2. All swaths were 9.1 meters in width and began on a south-to-north orientation. During trials 3 and 10 the aircraft flew directly over tree rows; for the remaining trials considered here, the aircraft flew between rows.

## 2.2 Spray Site

Figure 1 shows that the Withlacoochee orchard is divided by a service road. During the field test, the area north of the road contained stands of slash pine, and the area south of the road was planted with stands of Ocala sand pine. For the remainder of this report, the area north of the road will be referred to as the slash pine orchard, and the area south of the road will be referred to as the Ocala sand pine orchard. Both orchards together will be referred to as the test area.

The surrounding terrain is gently rolling (Barry et al., 1982), with elevations varying between 15 and 46 meters above sea level. In the test area, trees were every 4.5 meters in north-south rows, separated by 9.1 meters; tree rows extended 366 meters north and south of the service road. Because of different tree dimensions and needle density, the Ocala sand pine orchard was denser than the slash pine orchard. Sample tree locations are shown as solid circles in Figure 1, and are numbered 1 through 12. Eight of the sample trees were in the slash pine orchard, and four were in the Ocala sand pine orchard.

Deposition sampling was made at the canopy top, at three levels in the tree crown, and on the orchard floor. Beverage can samplers covered with Kromekote card material were used in the canopy, and Kromekote cards in flat plastic holders were used at ground

level. Just below the top of the canopy (0.15 meters), can samplers were suspended from a line stretched east-west across the tree rows at the position of the sample trees, as shown in Figure 2. Canopy sampling lines extended to one tree row east and west of the sample trees, and cans were placed at 1.8 meter intervals between the trees along each line. Canopy lines are designated according to the sample trees on which they are suspended: thus, canopy line 3-4 is suspended through sample trees 3 and 4. There were six canopy lines altogether, four in the slash pine orchard (lines 1-2, 3-4, 5-6, and 7-8) and two in the Ocala sand pine orchard (lines 9-10 and 11-12).

Kromekote-wrapped cans were also placed in the upper crown, mid-crown, and lower crown of the sampling trees at the four cardinal directions (Figure 3), for a total of twelve cans per sample tree. These cans were suspended from the ends of branches.

Figure 2 also shows the placement of the ground sampling lines. Ground lines were placed beneath the sample trees, and extended two rows east and west of the sample trees. Cards were laid at intervals of 0.9 meters along each sampling line. There was also a ground sampling line along the middle of the service road between orchards; this line was 198 meters long and cards were placed every 3 meters along it. Data from this sampling line were used to generate droplet size data (mass and number median diameter). Droplet size data are discussed in Section 3 of this report.

Drift was monitored along the orchard perimeter by using both cards and cans. On February 20, two drift studies were conducted with the Hughes 500C helicopter. The first used trees around the orchard perimeter. Mylar-wrapped cans on 1.5-meter stakes and Kromekote card samplers placed at ground level were positioned as shown in Figure 4. The second drift study consisted of six special trials over an open area of the orchard to assess the drift potential of a water base spray with and without the drift control polymer Nalco-trol. For this study, Kromekote card samplers were placed on the ground, as shown in Figure 5.

Orchard characteristics at the time of the field trials are given in Table 3 for the two types of pine. For the purposes of the FSCBG simulation, the test area must be assumed to be uniformly distributed for each type of tree. The tree envelopes used in the FSCBG canopy model are based on typical tree dimensions (average widths and heights as measured during the field test), given in Rafferty et al. (1982). As previously mentioned, in addition to different tree shape, the foliage of the Ocala sand pine is denser than that of the slash pine.

Table 4 shows the actual tree dimensions for the twelve sample trees. It is readily apparent that there is significant scatter in the height and circumference of the sample trees. In fact, all of the sample trees in the slash pine orchard are taller than its stated mean canopy height of 12.0 meters (Rafferty et al., 1982 and J.W. Barry, private communication, 1988). The mean height of the Ocala pine sample trees is closer to the stated mean canopy height of the Ocala orchard (14.0 meters, Rafferty et al., 1982 and J.W. Barry, private communication, 1988). In addition to scatter in tree height and circumference, there were apparently gaps in each orchard. Barry et al. (1982) show a more detailed orchard layout in which undersized or thinly branched trees are indicated, and it is clear that both canopies were not uniform.

The beverage can samplers suspended in the canopy lines as well as those placed throughout the sample trees were wrapped with Kromekote card material, with a 0.8 cm disc of Kromekote card on top. Mylar was also used on can samplers and ground samplers in trials 5, 6, 7, and 10, to collect the spray drops that contained Manganese Sulfate ($MnSO_4$) tracer. After trial 3, foliage from both types of pine was collected and evaluated for number of drops deposited per centimeter of needle length.

Drop deposition data from the tops of the cans in the canopy lines and ground deposition data are evaluated in Section 3 of this report. Canopy deposition data (from beverage can samplers and from foliage) are evaluated in Section 4. Downwind drift data, including six special trials conducted on February 20 in open terrain, are discussed in Section 5.

## 2.2 Meteorological Measurements

A 16-meter tower located near the center of the orchard (as shown in Figure 1) measured azimuthal and vertical wind directions and wind speed with MRI Vectorvanes (Barry et al., 1982). A Tethersonde balloon located in a small, open area near the western edge of the spray block measured wind direction, wind speed, temperature and relative humidity to heights of 70 meters during most trials. Wind speed and wind direction data were used during the trials to decide on which row (or aisle) to begin spraying (Barry et al., 1984).

Table 5 summarizes the meteorological conditions during each trial evaluated in this report). Note that the temperature and relative humidity data for trials 2 and 13 were recorded at the tower, but temperature and relative humidity data for all other trials evaluated here were recorded by Tethersonde. The height at which the Tethersonde data were recorded is not indicated. Since wind data are only available at 16 meters, there are no wind data available within the canopy (mean canopy height for Slash pine was 12 meters).

The trials were conducted over nine days, and at all different times of day, as indicated in Table 1. Wind direction, wind speed, temperature and relative humidity measurements varied considerably over the course of the trials, even during the same day. Trials 2 and 3 were both conducted on February 15, one mid-morning and one mid-afternoon, and both show similar wind data. However, wind data recorded for trials 5 and 6 (conducted on February 16), and 11 and 13 (conducted on February 20) were not similar. It is important to note that meteorological variables can vary significantly over even a short period of time, and from location to location over the test area.

Meteorological data recorded during the special drift trials (conducted on February 20) are presented in Section 5.

## 2.3 Aircraft and Spray Systems

Table 6 summarizes the aircraft and spray systems used in each of the Withlacoochee trials. The fixed-wing airplane flown was a Stearman biplane, with a spray system consisting of 27 D6-46 hydraulic nozzles placed along a boom mounted

immediately aft of the lower wing of the airplane (Rafferty et al., 1982). The helicopter flown was a Hughes 500C whose spray system consisted of the normal right and left booms (J.W. Barry, private communication), each with 24 D2-45 nozzles. Booms on the helicopter were mounted just below the fuselage. Flight speeds of each aircraft were as shown.

Release height above the mean canopy top was 6.1 meters for trials 2 and 3, and 1.5 meters for all other trials of interest. An application rate of 5.0 gallons per acre was sprayed for all of the trials, with the exception of trial 7, during which the spray system malfunctioned. The tank mix consisted of water, 48 ounces of Rhodamine liquid BX dye per 100 gallons, and 5 ounces of Nalco-trol per 100 gallons. For trials 5, 6, 7, and 10, the tank mix also included technical grade Manganese Sulfate, mixed at a rate of 10 pounds per 100 gallons.

The spraying aircraft flew multiple passes over portions of the orchard that contained sample trees, as previously described and shown in Table 2.

## 2.4 Data Reduction Procedure

Kromekote cards were analyzed on the University of California Quantimet image analyzer and the resulting output was evaluated by the automatic spot counting and sizing data program (ASCAS, Young et al., 1977). Drop deposition data (in drops per square centimeter) were generated for each top-of-can sampler on the canopy lines, and mass deposition data (in milligrams per square meter) were generated for the ground cards.

Coverage of the can samplers' vertical surface by the spray drops was assessed on the basis of percent of the total surface area of the cylinder covered (Barry et al., 1984). The number of drops on sides of can samplers was not recorded. Side-of-can coverage data are not addressed here.

The Mylar can samplers were assayed by atomic absorption in the laboratory after Manganese Sulfate tracer was washed from the sampler substrate (Barry et al., 1984). Estimates of mass deposition were made and presented in Barry et al. (1982) as micrograms of Manganese Sulfate recovered, as well as equivalent gallons per acre (based on the ratio of 1 part Manganese Sulfate to 83.37 parts water, for an emission rate of 5.0 gallons per acre).

The special drift study done on February 20 was conducted in open terrain, with Kromekote ground cards. Drop and volume deposition data were generated for six trials, which are discussed in Section 5 of this report.

## 2.5 Field Test Deposition Data

Examples of the field test deposition data available for each trial evaluated in this report (except the special drift trials) are shown in Figures 6 and 7. Two sets of data are shown: average mass deposition on the ground, in milligrams per square meter (Teske,

1989); and number of drops per square centimeter measured along canopy lines 1-2 and 3-4 (slash pine) and 9-10 and 11-12 (Ocala sand pine), as presented by Barry et al. (1982).

Ground deposition data are available as average mass deposition along tree rows (J.W. Barry, private communication, 1988). Teske (1989) notes, in a previous study of the Withlacoochee trials, that the actual data along all available card rows would show scatter. The data are presented with x=0 over tree row 10 (just to the west of the sample trees, as indicated in Figure 1) to be consistent with previous data comparisons done by Barry at et al. (1982) and Teske (1989). Positive x is distance to the east of tree row 10. Ground deposition lines were placed between tree rows 10 and 5, as shown in Figure 2 (between x=0 and 46 meters in this coordinate system). Deposition data from the ground line placed along the service road are apparently not included in the average data shown here, since the field test average deposition data are available over a 49.5 meter distance.

Peak mass deposition measured during the fixed-wing aircraft trials was between 2500 and 3700 mg/sq m, with the exception of trial 7, during which a pump bearing burned out. Only 15 gallons of spray were applied during trial 7; consequently, much less mass deposition was observed, with a peak of only 800 mg/sq m. Peak mass deposition for helicopter trials 10 and 11 was between 4000 and 5000 mg/sq m; for trial 13, lower mass deposition was observed. Observed mass deposition data for each of the trials are shown in the next section.

Canopy data presented in Figure 7 show four of the canopy sampling lines in trial 2. The top plot in Figure 7 shows two of the lines that were placed between tree rows 9 and 6 in the slash pine orchard, and the bottom plot shows the two lines placed between tree rows 7 and 4 in the Ocala pine orchard. Mean deposition along each canopy line is also shown. Once again, data are presented with position x=0 over tree row 10, to be consistent with the ground deposition plots. In this coordinate system, canopy lines were strung from x=9.1 meters to x=36.4 meters (tree rows 9 to 6) in the slash pine orchard and from x=27.3 meters to x=54.6 meters (tree rows 7 to 4) in the Ocala pine orchard.

There are no canopy data available for trial 7, and there are only data from the slash pine orchard for trial 6. Note that there is a great deal of scatter in the canopy line data for trial 2; this amount of scatter is typical of all the canopy line data available. Barry et al. (1982) note that some counts of droplets on the tops of the beverage cans were extremely difficult to make due to a combination of factors: rain damage, which diluted the dye and caused excessive drop spreading; wind effects, which spread the droplets into each other; and counting error for sampler discs with high droplet concentration.

Table 7 shows the average field test deposition measured along canopy lines, by tree type, for each trial (except trial 7). As previously mentioned, all canopy line data shown in this report are from the tops of the beverage can samplers. For all trials shown in the table, more drops were counted on sampler tops in the slash pine canopy than in the denser Ocala sand pine canopy.

After trial 3, needles were collected from four sample trees, two in each orchard, for examination and assessment of drop deposition. Several fascicles were collected from each cardinal direction at three crown levels in each of the four sample trees: upper crown, middle crown and lower crown. Five needles were selected randomly from each of the

fascicles, and were then examined for the presence of drop stains (Barry et al., 1982). Table 8 shows the mean number of drops per centimeter of needle length measured at each crown height for each of the sample trees.

In keeping with the canopy line data, more drops were counted per centimeter of slash pine needle than were counted per centimeter of Ocala pine needle. Barry et al. (1984) note that the dense foliage of the Ocala pines would tend to impede the downward velocity of the spray cloud and the needles would more efficiently scavenge spray drops before being deposited on the samplers; penetration of spray into the crown would be impeded. Thus, for the same amount of spray, the denser Ocala pine canopy collects fewer drops on each element of its foliage than the more open slash pine canopy. One of the conclusions reached by Barry et al. (1982 and 1984) was that more spray drops are required for comparable coverage of densely foliated pines than are required for the less dense species.

Table 1: Scope of the 1980 Withlacoochee State Seed Orchard Trials

| Trial | Time | Date | | Type Applicator | Remarks |
|---|---|---|---|---|---|
| 1 | 1554 | 2-13 | | Stearman | |
| 2 | 1008 | 2-15 | * | Stearman | |
| 3 | 1507 | 2-15 | * | Stearman | |
| 4 | 1718 | 2-15 | | FMC speed sprayer[1] | |
| 5 | 1214 | 2-16 | * | Stearman | with Manganese Sulfate |
| 6 | 1633 | 2-16 | * | Stearman | with Manganese Sulfate |
| 7 | 0942 | 2-18 | * | Stearman | with Manganese Sulfate; spray system malfunction |
| 8 | 0734 | 2-19 | | Stearman | |
| 9 | 1557 | 2-19 | | Orchard sprayer[2] | |
| 10 | 1707 | 2-19 | * | Hughes 500C | with Manganese Sulfate |
| 11 | 0748 | 2-20 | * | Hughes 500C | |
| 12 | 1043 | 2-02 | | Hughes 500C | |
| 13 | 1757 | 2-20 | * | Hughes 500C | |
| 14 | 0749 | 2-21 | | Hughes 500C | no Nalco-trol |
| 15 | 1110 | 2-21 | | FMC speed sprayer | |
| 16 | 1400 | 2-21 | | Orchard sprayer | |
| 17 | 1509 | 2-21 | | Orchard sprayer | |
| 18 | 0800 | 2-22 | | Orchard sprayer | |

Unless otherwise noted, the tank mix consisted of water, 48 oz. Rhodamine liquid BX dye per 100 gallons, and 5 oz. Nalco-trol per 100 gallons. Manganese Sulfate (technical grade) was mixed at a rate of 10 pounds per 100 gallons.

* These trials are evaluated in this report.

1. FMC ground sprayer Md. LV 650.
2. Bean-type orchard sprayer mounted on stake body truck.

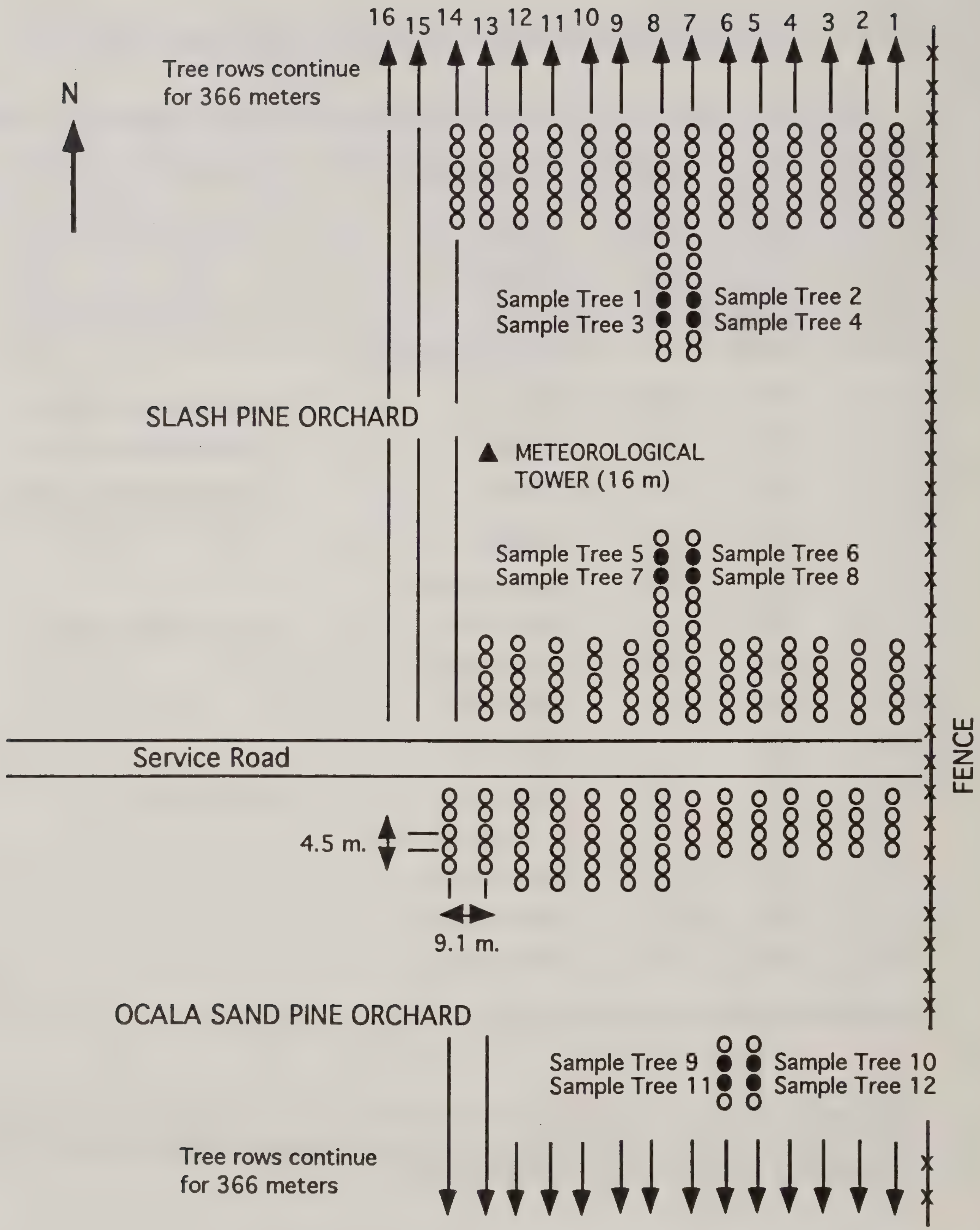



Figure 1: Withlacoochee State Seed Orchard: diagram of the test area established for the 1980 spray trials. Sampling trees are indicated as solid circles, and by numbers 1-12. Meteorological tower indicated by solid triangle.

Table 2: Swaths by Trial and Tree Row Number

| | Swaths[1]/Tree Row | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trial | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2 | 10-11[2] | 9-10 | 8-9 | 7-8 | 6-7 | 5-6 | 4-5 | | | |
| 3 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | | |
| 5 | 4-5 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | |
| 6 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | |
| 7 | 9-10 | 8-9 | 7-8 | 6-7 | 5-6 | 4-5 | 3-4 | 2-3 | 1-2 | |
| 10 | 10 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
| 11 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | |
| 13 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | |

1. All swaths start in a south-to-north direction over south-to-north tree rows.

2. When two rows are indicated, the aircraft flew between them. Note that in trials 5 and 10, the aircraft flew the same flight line twice.

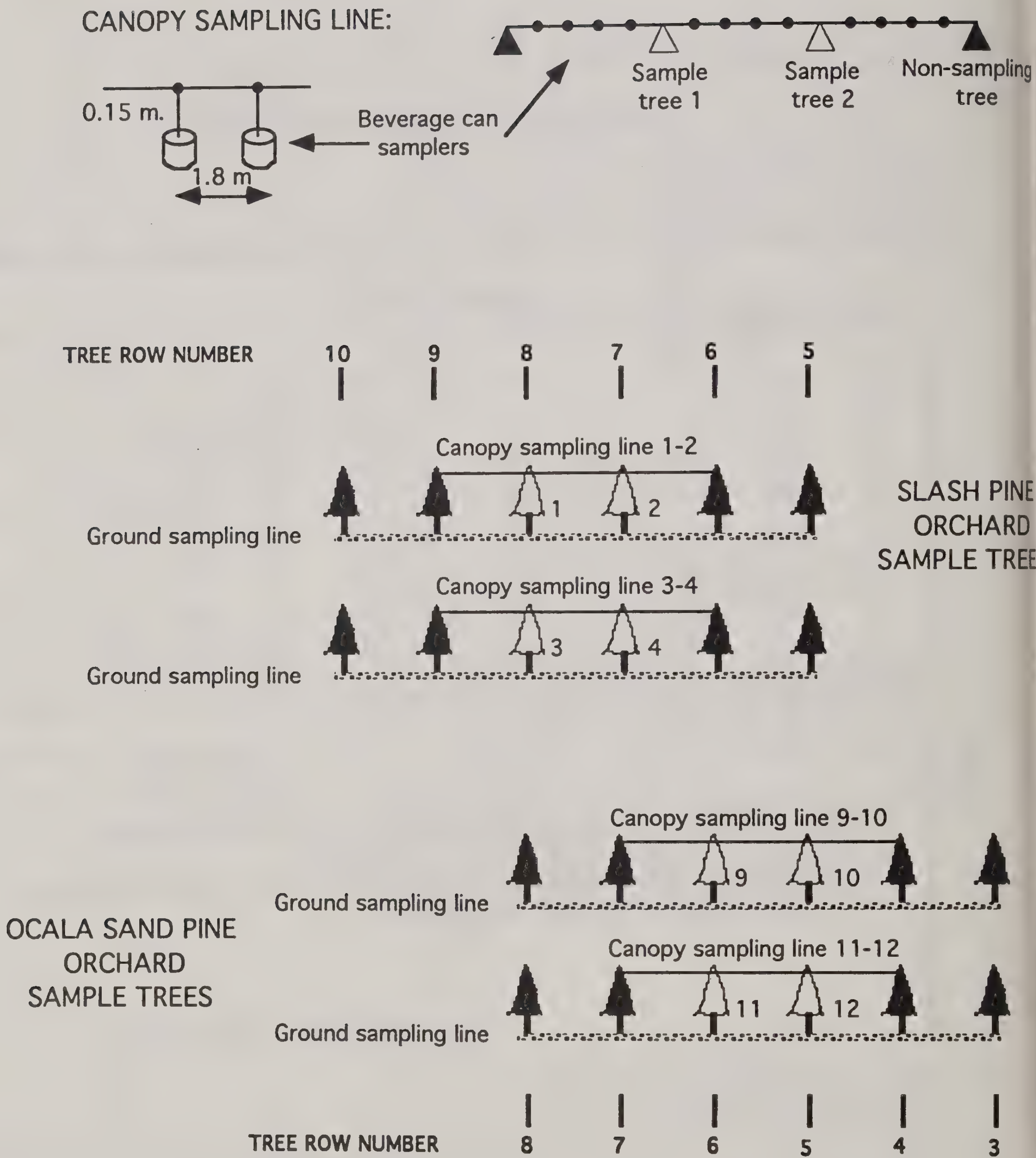
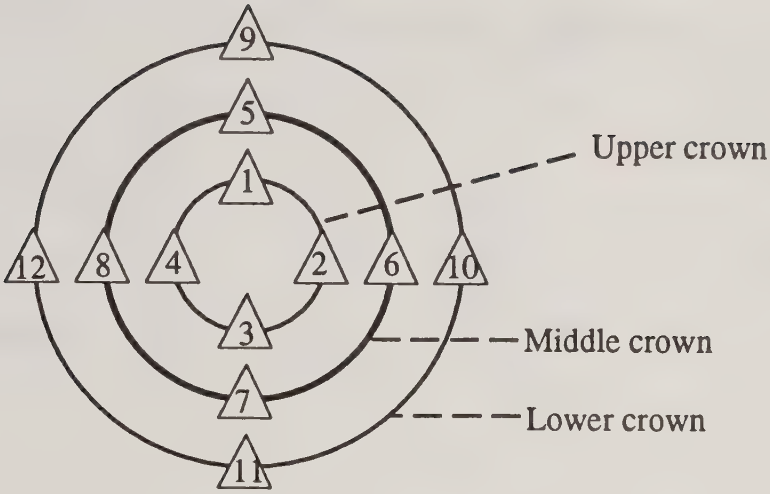



Figure 2: Canopy and ground sampling line placement in the slash and Ocala sand pine orchards.

TOP VIEW




SIDE VIEW

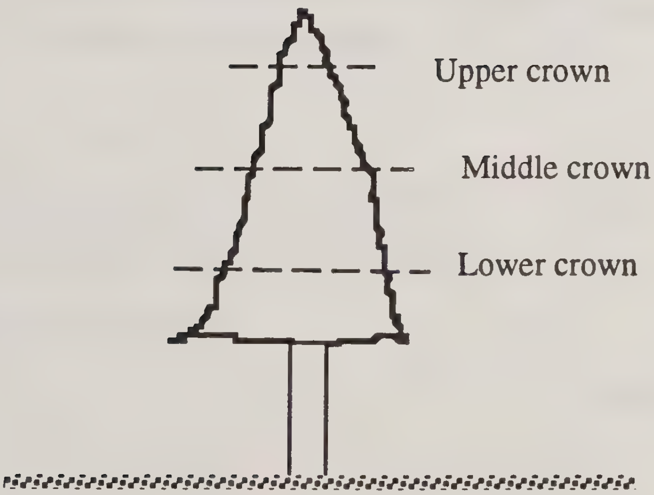



Figure 3: Placement of can samplers within sample tree crowns. Exact elevations of upper, middle and lower crown samplers varied from sample tree to sample tree. Upper crown elevation was approximately 92% of tree height; middle crown was between 69% and 84% of tree height; lower crown was between 52 and 68% of tree height.

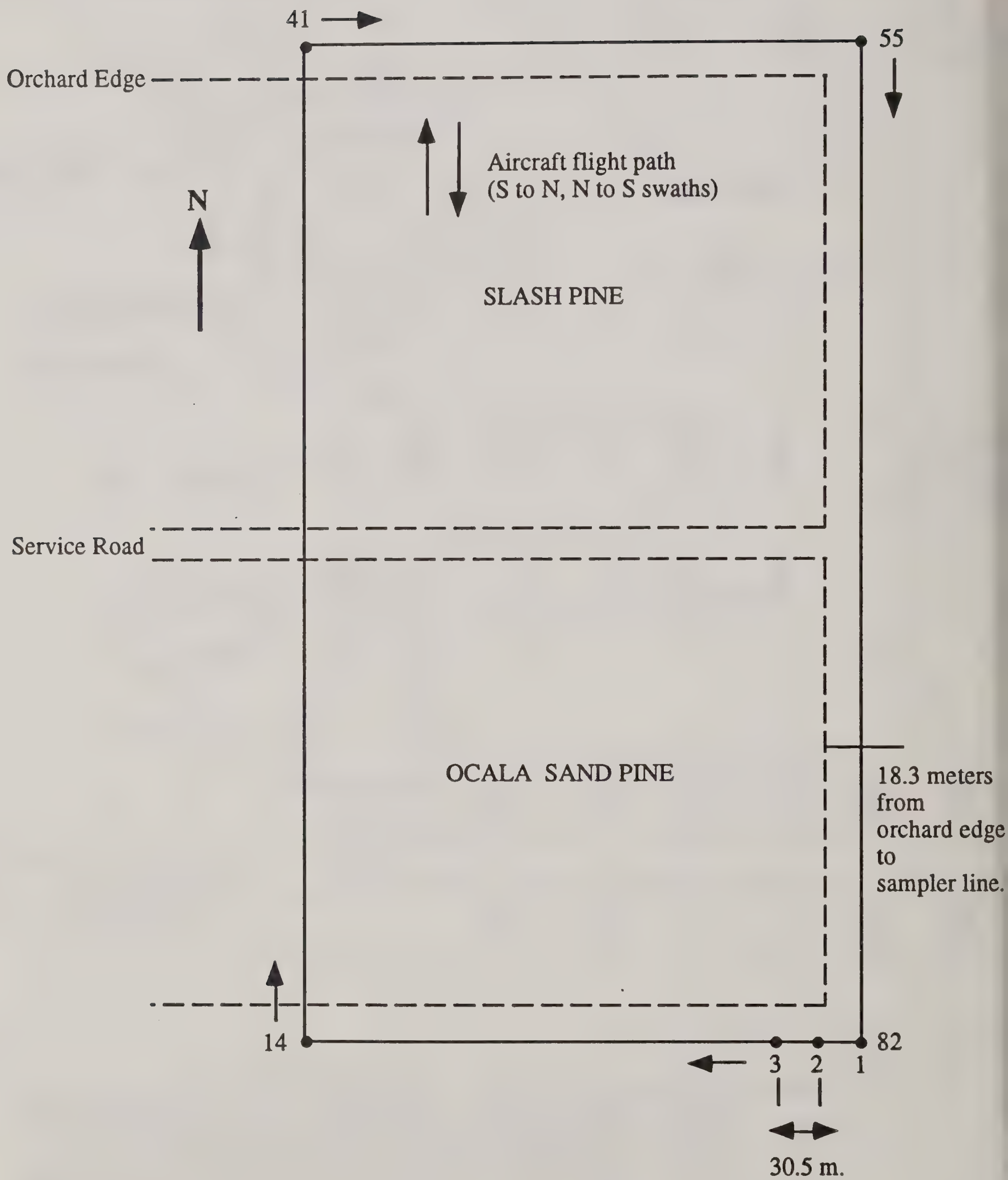



Figure 4: Placement of drift samplers around the orchard perimeter during trials 5, 7, 10, and 11 through 14. Drift samplers are numbered 1 through 82 as shown. Distance between samplers is 30.5 meters; from orchard edge to sampler line is 60 meters.

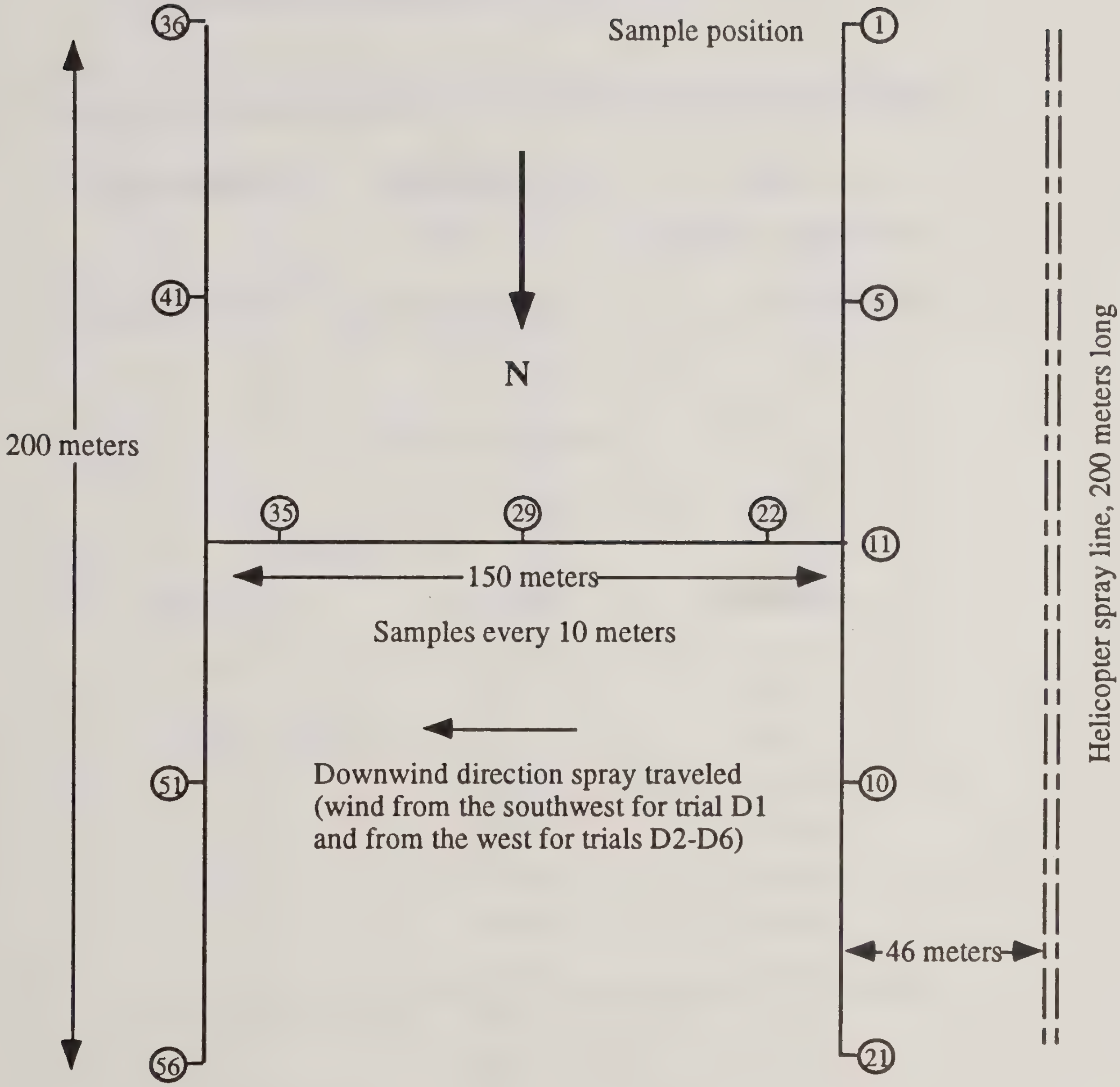



Figure 5: Diagram of the sampling array for the special drift trials conducted February 20, trials D1 through D6. Sampling array set up in open terrain, with samplers numbered as shown.

Table 3: Withlacoochee State Seed Orchard Characteristics

| | Slash pine | Ocala sand pine |
|---|---|---|
| Mean Canopy Height (m) | 12 | 14 |
| Stand Density | 96.8 stems/acre | 96.8 stems/acre |

TREE ENVELOPES:

| | Tree Width (m) | |
|---|---|---|
| Height (m) | Slash pine | Ocala sand pine |
| 1.0 | .21 | .31 |
| 2.0 | .19 | .30 |
| 3.0 | .19 | .30 |
| 4.0 | 3.8 | 7.2 |
| 5.0 | 6.6 | 7.1 |
| 6.0 | 6.2 | 7.8 |
| 7.0 | 5.8 | 7.1 |
| 8.0 | 5.4 | 6.4 |
| 9.0 | 5.0 | 6.1 |
| 10.0 | 4.0 | 5.9 |
| 11.0 | 3.3 | 5.4 |
| 12.0 | 1.6 | 4.4 |
| 13.0 | -- | 3.0 |
| 14.0 | -- | 1.5 |

Table 4: Sample Tree Dimensions

| Sample Tree | Circumference (m) | Height (m) |
|---|---|---|
| (Slash pine) | | |
| 1 | 6.7 | 12.2 |
| 2 | 8.5 | 12.4 |
| 3 | 10.0 | 13.8 |
| 4 | 9.1 | 13.8 |
| 5 | 6.6 | 12.5 |
| 6 | 11.0 | 15.1 |
| 7 | 11.0 | 12.5 |
| 8 | 8.2 | 12.4 |
| (Ocala sand pine) | | |
| 9 | 11.7 | 15.2 |
| 10 | 11.6 | 13.5 |
| 11 | 11.4 | 12.9 |
| 12 | 11.8 | 13.9 |

Average sample tree height: Slash pine = 13.1 ± 1.0 meters
Ocala sand pine = 13.9 ± 0.8 meters

Average sample tree circumference: Slash pine = 8.9 ± 1.6 meters
Ocala sand pine = 11.6 ± 0.2 meters

Table 5: Meteorological Data Recorded During the Withlacoochee Spray Trials

| | | | Wind (at 16 meters) | |
|---|---|---|---|---|
| Trial | Temperature (deg C) | Relative Humidity (%) | Speed (m/s) | Direction (deg) |
| 2 | 14.4[1] | 100[1] | 1.02 | 23 |
| 3 | 19.4 | 74 | 1.10 | 20 |
| 5 | 21.2 | 67 | 3.15 | 214 |
| 6 | 25.0 | 52 | 4.21 | 256 |
| 7 | 8.5 | 68 | 6.2 | 33 |
| 10 | 20.6 | 55 | 1.76 | 360 |
| 11 | 7.0 | 95 | 0.94 | 305 |
| 13 | 18.3[1] | 61[1] | 1.90 | 265 |

1. Measurement taken at tower location.

Table 6: Aircraft and Spray Systems for the Withlacoochee Spray Trials

| Parameter | Stearman | Hughes 500C |
|---|---|---|
| Aircraft Weight (kg) | 1403.0 | 1154.0 |
| Wing Span or Rotor Diameter (m) | 11.46 | 7.88 |
| Speed (m/s) | 40.1 | 11.2 |
| Release Height Above Canopy (m) | 6.1[1] / 1.5 | 1.5 |
| Swath Width (m) | 9.1 | 9.1 |
| Nozzle Type | D6-46 | D2-45 |
| Nozzle Orientation | down 30° | straight back |
| Number of Nozzles | 27 | 48[2] |
| Boom Pressure (psig) | 40 | 40 |
| Application Rate (gal/acre) | 5.0 | 5.0 |

1. Release height for trials 2 and 3 was 6.1 m; 1.5 m for all other trials.

2. The helicopter spray system consisted of two booms with 24 nozzles each.

Mean canopy height for slash pine orchard = 12 m. Mean canopy height for Ocala sand pine orchard = 14 m.

The formulation sprayed is described in Table 1.

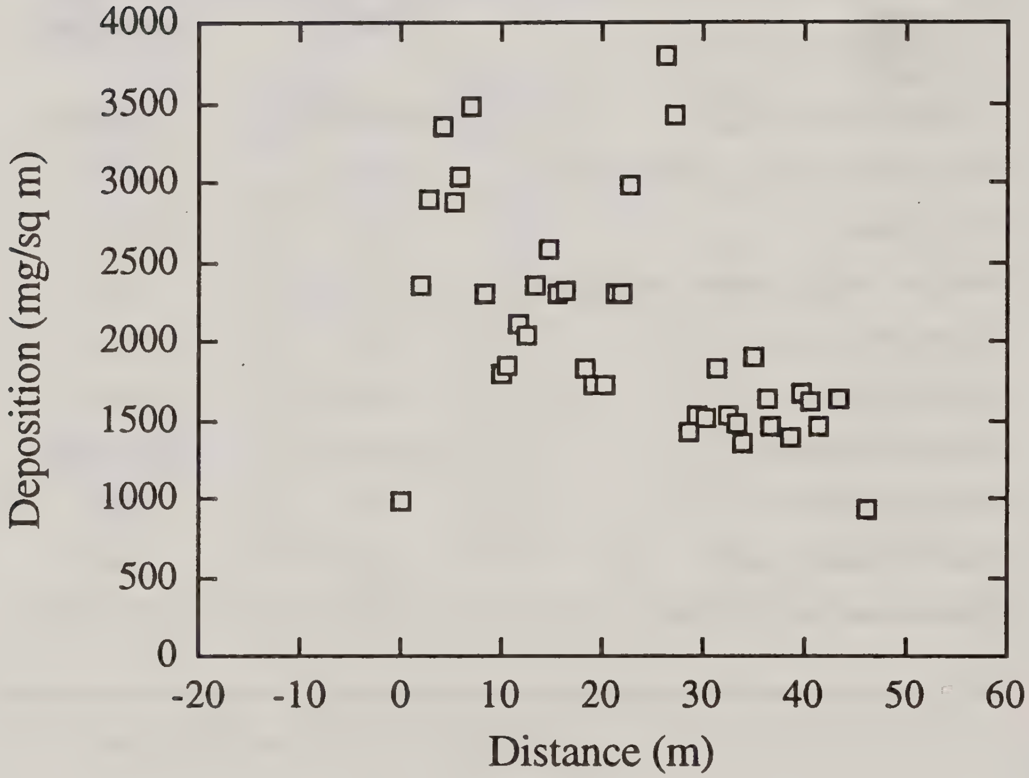



Figure 6: Average mass deposition observed at ground level, Withlacoochee trial 2.

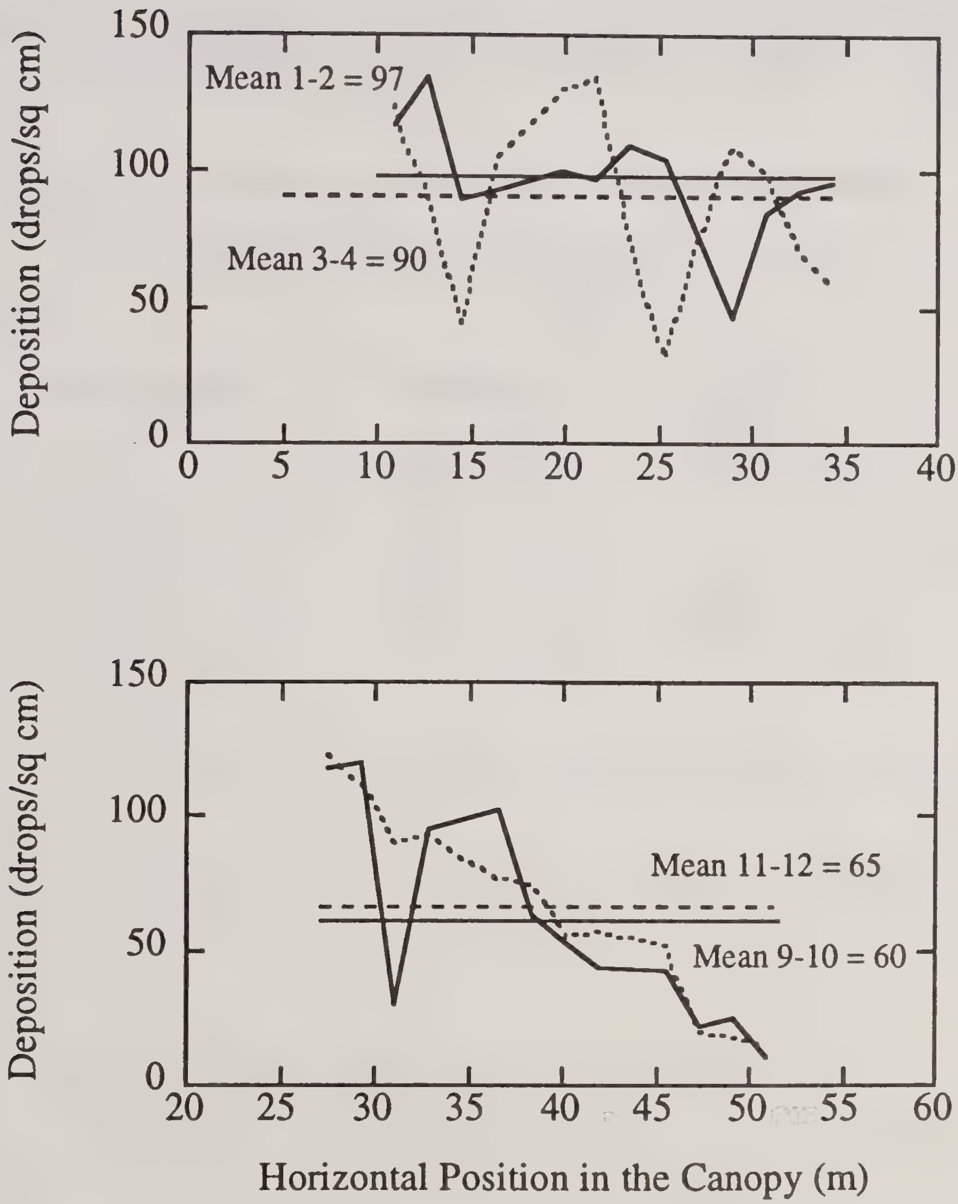



Figure 7: Withlacoochee trial 2: Drop deposition observed on samplers from canopy lines 1-2 and 3-4 (slash pine orchard) and canopy lines 9-10 and 11-12 (Ocala sand pine orchard). Solid lines indicate canopy lines 1-2 (top) and 9-10 (bottom). Dashed lines indicate canopy lines 3-4 (top) and 11-12 (bottom). Mean deposition in drops per square centimeter is shown for each canopy line. Canopy position 0 is at tree row 10, positive pointing east.

Table 7: Average Drop Deposition in the Orchard Canopy by Tree Type, as Measured on the Tops of Beverage Can Samplers Along Canopy Lines

| | Average Drop Deposition (drops/sq cm) | |
|---|---|---|
| Trial | Slash pine | Ocala sand pine |
| 2 | 94 | 63 |
| 3 | 75 | 45 |
| 5 | 75 | 65 |
| 6 | 30 | -- |
| 10 | 75 | 50 |
| 11 | 80 | 65 |
| 13 | 65 | 60 |

Table 8: Mean Number of Drops per Centimeter of Needle Length on Selected Sample Trees, Trial 3, at Three Crown Heights

| | Mean Drops per Centimeter of Needle Length[1] | | | |
|---|---|---|---|---|
| Location | Slash pine | | Ocala sand pine | |
| | Tree 1 | Tree 2 | Tree 9 | Tree 10 |
| Upper Crown | 6.8 | 15.6 | 1.8 | 0.8 |
| Middle Crown | 3.9 | 17.7 | 1.3 | 1.3 |
| Lower Crown | 3.4 | 10.7 | 1.0 | 0.5 |

1. Mean length of slash pine needles = 20 cm (approximately)
   Mean length of Ocala sand pine needles = 10 cm (approximately)

# 3. FSCBG Simulation of Ground Deposition Data

Aircraft and spray system variables, canopy characteristics, and meteorological conditions recorded for Withlacoochee trials 2, 3, 5, 6, 7, 10, 11, and 13 were used to simulate field test deposition data with the FSCBG aerial spray model, described in the introduction. The operation of FSCBG is further described in Teske and Curbishley (1991, 1994).

Aircraft and spray system variables for the two aircraft used in the trials were shown previously in Table 6. Drop distribution data for the nozzle spray systems used with the Stearman biplane and the Hughes 500C helicopter are given in Tables 9 and 10, respectively. Drop distribution data for the D6-46 nozzles used with the Stearman biplane are given by Rafferty, et al. (1982).

Although drop distribution data for the D2-45 nozzles used with the Hughes 500C are given in Rafferty et al.(1982), there is an entry for this nozzle in the FSCBG library, at the correct airspeed, which gives a more fully defined distribution (Table 10). An initial attempt at modeling the helicopter trials with the distribution given in Rafferty et al. (1982) resulted in good agreement of predicted ground deposition with field test data, but underprediction of the number of drops deposited in the canopy. The distribution shown in Table 10 gives very similar predicted mass deposition on the ground, and gives a much closer prediction for number of drops deposited in the canopy, and so will be used in this report.

As previously mentioned, meteorological data for the trials were only recorded at 16 meters, 2 meters above the mean canopy height of the Ocala sand pine orchard and 4 meters above the mean canopy height of the slash pine orchard. In some cases, specific meteorological data were recorded at a different, unknown, height (Table 5 shows those meteorological variables recorded by the Tethersonde balloon). Furthermore, since the meteorological tower was located near the center of the slash pine orchard (Figure 1), data were not necessarily recorded near a specific set of sample trees. For most of the trials considered, the spray was released close to the canopy and was affected mainly by the aircraft wake, its turbulence, and canopy meteorology. For the purposes of FSCBG modeling, since no data were recorded within the canopy, canopy meteorology was assumed to be similar to that measured by the tower, but wind speed was reduced by a factor of two since data were recorded above the canopy.

The presence of a canopy removes spray material by permitting its impaction on vegetation. The probability that a drop will penetrate a canopy depends on the total number and size of vegetative elements encountered. Since the orientation of the vegetative elements is assumed to be random, the probability of penetration for a given path length will be the same for all directions. Teske et al. (1993a) describes the canopy penetration model used in FSCBG in detail. The probability of penetration, the probability that a drop traversing along its trajectory will penetrate a typical single tree envelope, is a value that is either assigned according to tree type based on foliage density and envelope dimensions, or determined from optical measurements as a function of sun incidence angle. Rafferty et al. (1982) gives the probabilities of penetration of slash and Ocala sand pines as 0.38 and

0.13, respectively. These numbers reflect the difference in foliage density previously mentioned.

The position of the spray aircraft during the trials is given in Table 2, and the length of the tree rows in the north-south direction is known (366 meters to the north and south of the service road). Spray was turned on at the beginning of the first tree row (366 meters south of the service road) and turned off at the end of the last tree row. To simulate the amount of spray descending into the canopy, the spray aircraft was modeled to fly in 9.1 meter swaths as described in Table 2, starting in a south-north direction (as noted in Barry et al., 1982). Aircraft position between rows was assumed to be exactly in the middle of the rows. Crosswind effect was taken into account for the five trials which were flown with the Stearman biplane (trials 2, 3, 5, 6, and 7).

Each orchard was modeled separately, since the canopies are different (as indicated in Table 3). Predicted mass deposition on the ground under the slash pine and the Ocala sand pine canopies was very similar; predicted deposition for the two canopies was averaged, and is presented with the mass deposition observed during the field trials in Figures 8 to 15. As mentioned in the previous section, the coordinate system shown in the comparison plots positions x=0 over tree row 10, with positive x pointing east. This coordinate system is consistent with the coordinate system established in Barry et al. (1982) and Rafferty et al. (1982), as well as Teske (1989), for previous evaluations of the Withlacoochee data.

The two biplane trials which were flown at 6.1 meters over the canopy (trials 2 and 3) show the best correlation with field test data. The correlation coefficient, $R^2$, is 0.81 for trial 2 and 0.69 for trial 3. The rest of the biplane trials and all three helicopter trials were flown 1.5 meters over the canopy top. Although FSCBG predicts the level of deposition well for all of these trials, the shape of predicted deposition over the ground lines is somewhat different from the average mass deposition observed in each trial. Correlation to mass is not as good for these trials, although it is still good for an operational field test. Correlation to mass for trials 5, 7, 10 is $R^2 = 0.52$, 0.57 and 0.65, respectively. Correlation to mass for trials 6 , 11 and 13 is $R^2 = 0.41$, 0.40 and 0.48, respectively. There are several probable reasons why the trials flown at 1.5 meters show poorer correlation.

At such a low height over the canopy, foliage in the upper portion of the canopy was probably significantly disturbed by the passage of the aircraft (and particularly by the helicopter downwash), effectively changing the canopy profile. FSCBG assumes a uniform canopy; the canopy models used for each type of pine tree are based on typical tree dimensions and foliage characteristics, obtained when the trees are in an undisturbed state. Variations from these typical profiles, as well as non-uniformities in the canopy, would have affected penetration of the spray through the canopy, but cannot be accounted for in the model. Both the slash pine orchard and the Ocala pine orchard were not uniform (as discussed in Section 2.1, and shown in Table 4). Furthermore, as previously mentioned, meteorological data were recorded above the canopy (and above the release height of these six trials). Canopy meteorological parameters were most likely different from the recorded data; wind speed and direction, in particular, can be very different in the canopy than in the surrounding area. Spray descending through the canopy was affected primarily by conditions within the canopy.

Finally, although aircraft flight path was recorded and the orchard layout was clearly defined, there may have been some variation in the position of the aircraft, particularly for those trials when swaths were flown between tree rows. At least four swaths were flown over the ground deposition lines in each trial, and each swath was hand-flagged (J.W. Barry, private communication, 1996). Because several swaths were flown, a variation of even a few meters from the positions used to model a given trial could result in differences between the predicted deposition pattern and observed data. FSCBG predictions of deposition over each swath are combined for the prediction over the total length of the ground sampler lines. Field test deposition data for many of the trials do not show the same deposition pattern as the FSCBG predictions; this is especially apparent in Figure 13, which shows the predicted and observed mass deposition for trial 10. Since this was a helicopter trial, and the recorded wind direction was 360 degrees (exactly a headwind for the swaths flown south-to-north and exactly a tailwind for the swaths flown north-to-south), the FSCBG prediction for this trial shows clear peaks in deposition over the center of each swath flown over the ground lines. Field data for this trial does show peaks, but not as clearly; this is partly because the field data shown is an average of all of the ground line data, and could also be due to perturbation in wind speed or direction during the trial. Even though the FSCBG prediction looks very close, the correlation of predicted to observed mass deposition is only $R^2 = 0.65$.

Another indication that the aircraft position during flight may have differed from the recorded positions can be seen in Figure 13. The large peak at approximately 50 meters (in our coordinate system, this is 50 meters to the east of tree row 10) corresponds to a double swath: the aircraft flew the same flight line twice, once going south-to-north and once going north-to-south. Table 2 indicates that the double swath occurred over tree row 10; however, the field data indicates that it occurred over tree row 5 (45.5 meters in distance). FSCBG predictions were adjusted accordingly.

Any of the factors just mentioned (unevenly spaced swaths, variations in meteorological parameters from swath to swath, non-uniformity of the canopy, disturbance of the canopy top due to very low release height, and unknown canopy meteorology) may affect the eight Withlacoochee trials examined here. Nevertheless, the current predicted mass deposition profiles show good average correlation to mass for an operational field test: $R^2 = 0.57$.

Current predicted mass deposition profiles are also closer to observed data than either of the two previous evaluations of Withlacoochee field data (Rafferty et al., 1982 and Teske, 1989). Figure 16 shows the current FSCBG predicted mass deposition, the deposition predicted by Teske (1989) using the AGDISP code, the deposition predicted by Rafferty et al. (1982) using a previous version of FSCBG, and the field data, all for trial 2. The current version of FSCBG clearly does a better job of predicting the level and shape of deposition than the other two codes.

As mentioned in Section 2.1, droplet size data were generated for each trial from ground cards placed in the open, along the service road between orchards. These data are compared to FSCBG predicted droplet data in Table 11. Predicted droplet mass median diameter (MMD) and number median diameter (NMD) correlate well with observed droplet size data, particularly for the fixed-wing trials (2, 3, 5, 6, and 7). Figure 17 shows a scatterplot of the observed and predicted mass median diameter of the trials evaluated in

this report. A least squares line through the points gives a slope of 0.79; if only the fixed-wing data are considered, the slope is 0.92. Figure 18 shows a scatterplot of the observed and predicted number median diameter. A least squares line through these points gives a slope of 1.16.

Table 9: Drop Size Distribution Assumed for Trials 2, 3, 5, 6, and 7

| Mean Drop Diameter (micrometers) | Mass Fraction |
|---|---|
| 44.8 | 0.001 |
| 82.8 | 0.009 |
| 121.0 | 0.02 |
| 149.0 | 0.03 |
| 175.0 | 0.04 |
| 214.0 | 0.10 |
| 257.0 | 0.10 |
| 293.0 | 0.10 |
| 353.0 | 0.20 |
| 415.0 | 0.10 |
| 463.0 | 0.10 |
| 525.0 | 0.10 |
| 592.0 | 0.04 |
| 661.0 | 0.03 |
| 728.0 | 0.02 |
| 792.0 | 0.01 |
| | --------- |
| | 1.00 |

The distribution above is for the fixed-wing aircraft spray system (D6-46 hydraulic nozzles spraying water with Nalco-trol) used in the Withlacoochee State Seed Orchard Spray Trials (Rafferty et al., 1982).

Table 10: Drop Size Distribution Assumed for Trials 10, 11 and 13

| Drop Diameter (micrometers) | Mass Fraction |
|---|---|
| 56.0 | 0.0046 |
| 89.0 | 0.0103 |
| 122.0 | 0.0352 |
| 154.0 | 0.0829 |
| 187.0 | 0.1106 |
| 219.0 | 0.1251 |
| 252.0 | 0.1383 |
| 284.0 | 0.1283 |
| 318.0 | 0.1189 |
| 351.0 | 0.0868 |
| 382.0 | 0.0635 |
| 414.0 | 0.0419 |
| 447.0 | 0.0212 |
| 479.0 | 0.0164 |
| 512.0 | 0.0089 |
| 545.0 | 0.0031 |
| 578.0 | 0.0012 |
| 611.0 | 0.0018 |
| 644.0 | 0.0010 |
| | --------- |
| | 1.0000 |

The distribution above is for a D2-45 nozzle spraying water and Manganese Sulfate at 11.2 m/s, nozzles positioned straight back.

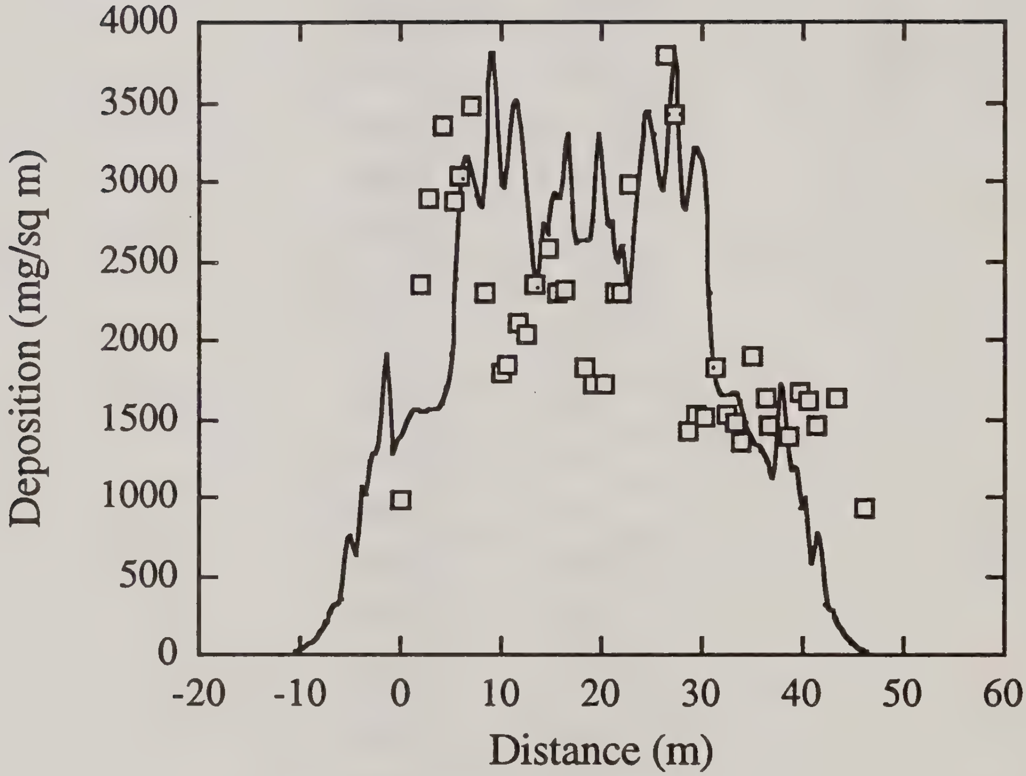



Figure 8: Trial 2 observed and predicted mass deposited on the ground, release height = 6.1 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.81$.

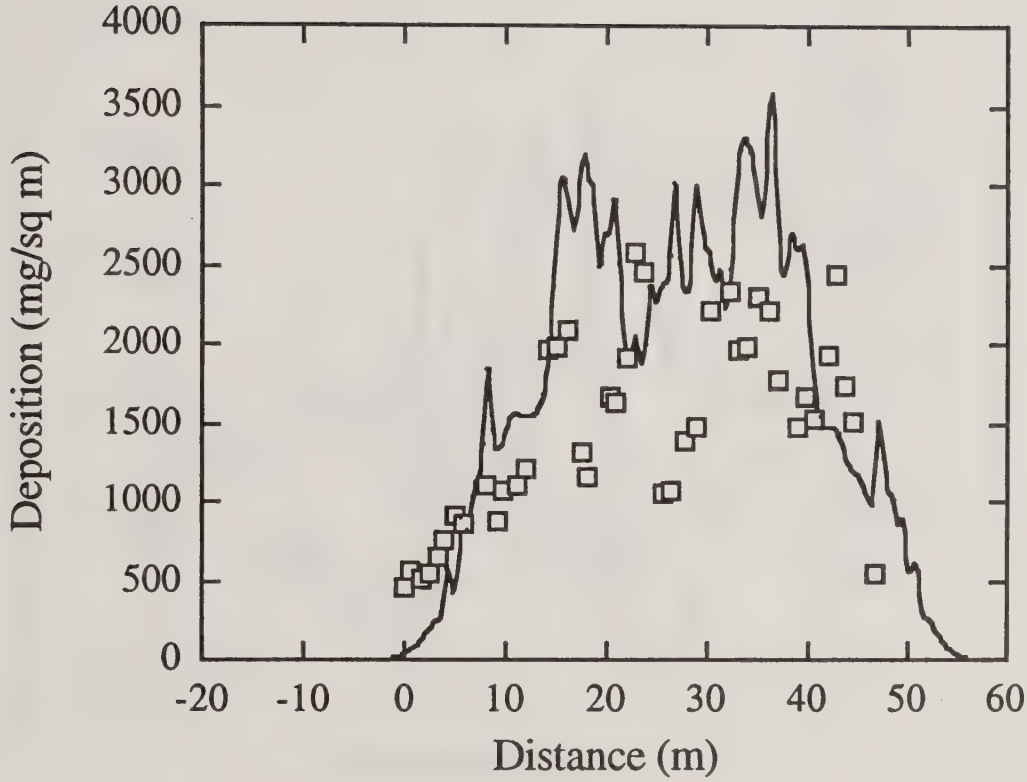



Figure 9: Trial 3 observed and predicted mass deposited on the ground, release height = 6.1 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.69$.

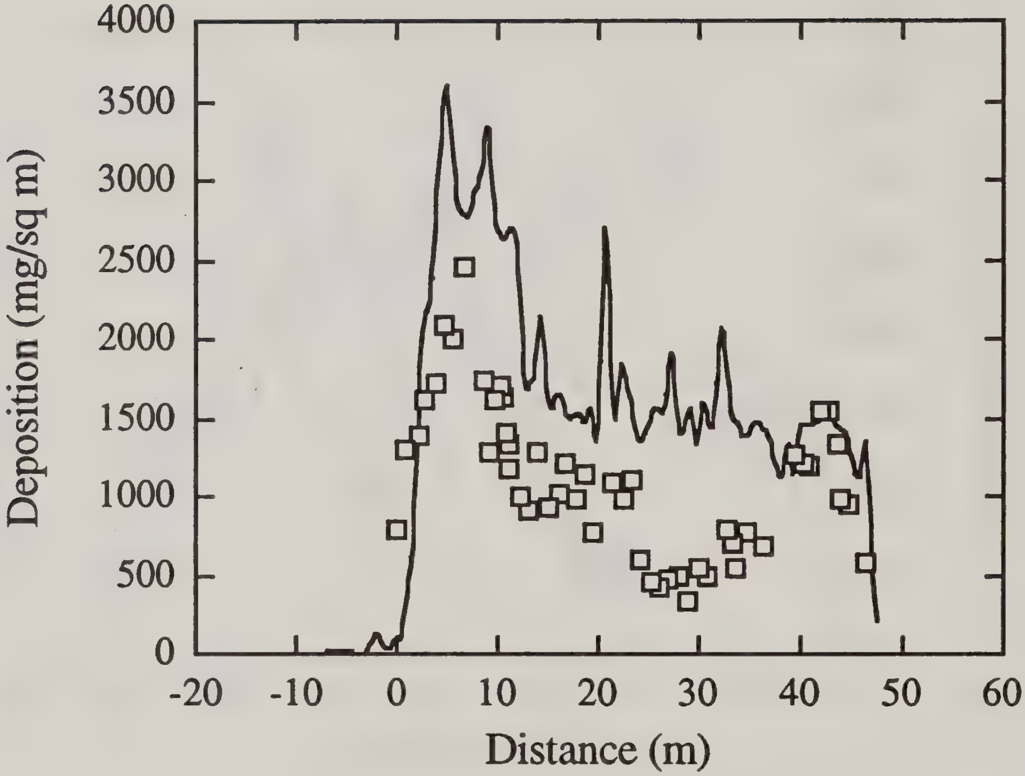



Figure 10: Trial 5 observed and predicted mass deposited on the ground, release height = 1.5 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.52$.

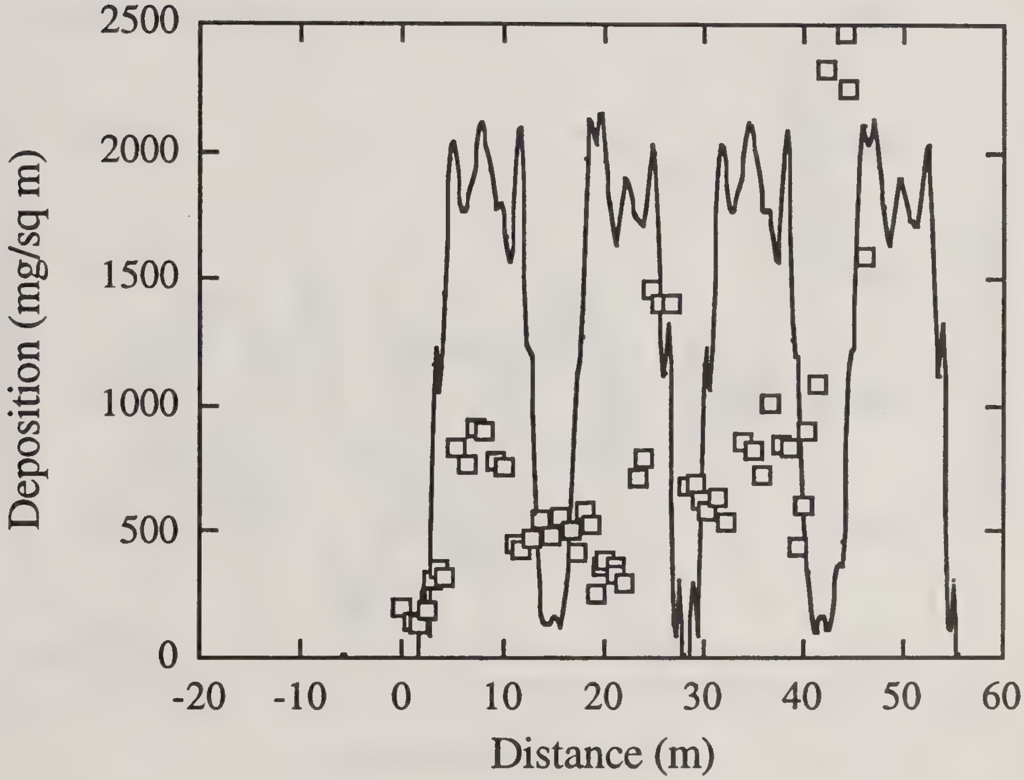



Figure 11: Trial 6 observed and predicted mass deposited on the ground, release height = 1.5 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.41$.

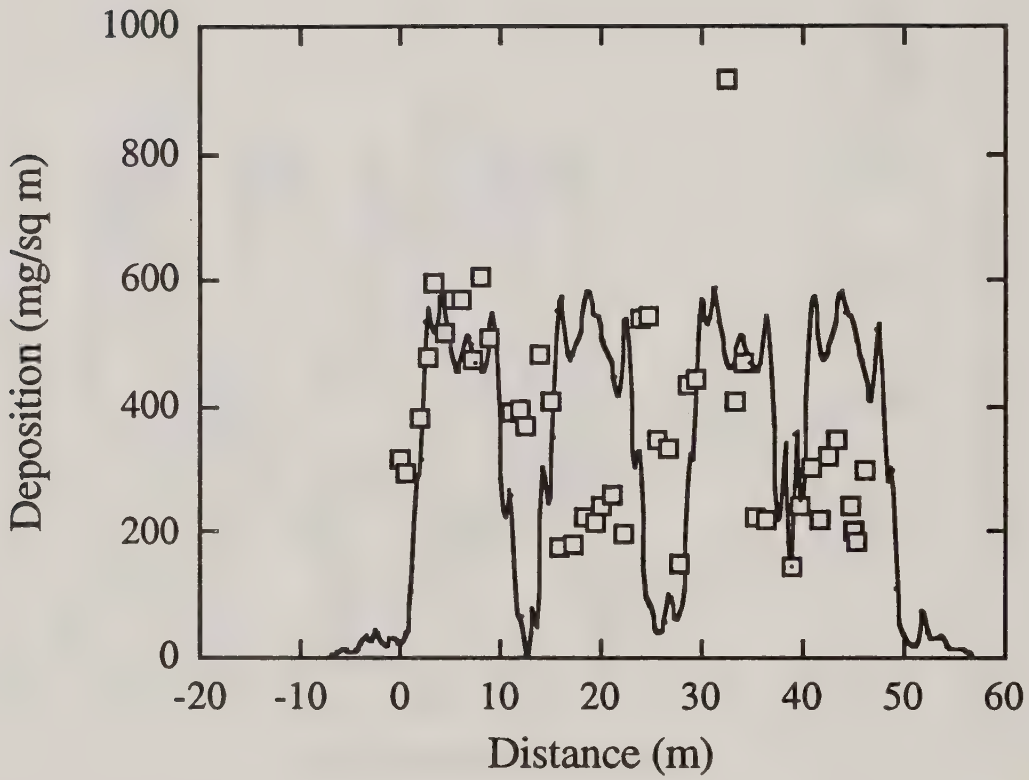



Figure 12: Trial 7 observed and predicted mass deposited on the ground, release height = 1.5 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.59$.

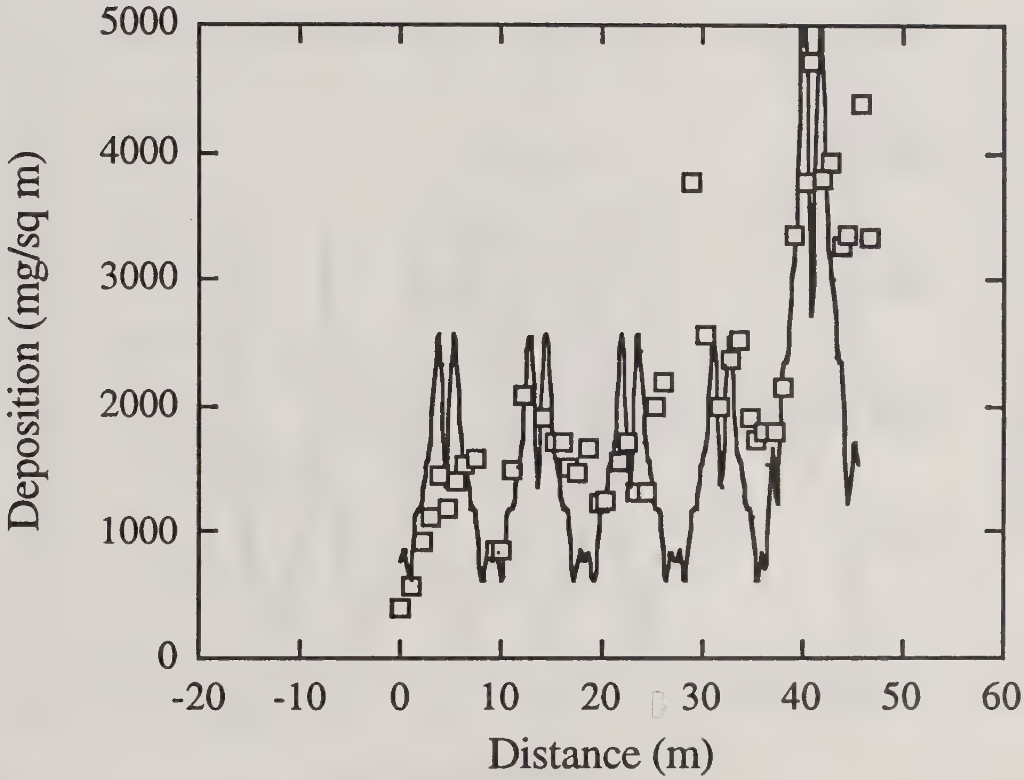



Figure 13: Trial 10 observed and predicted mass deposited on the ground, release height = 1.5 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.65$.

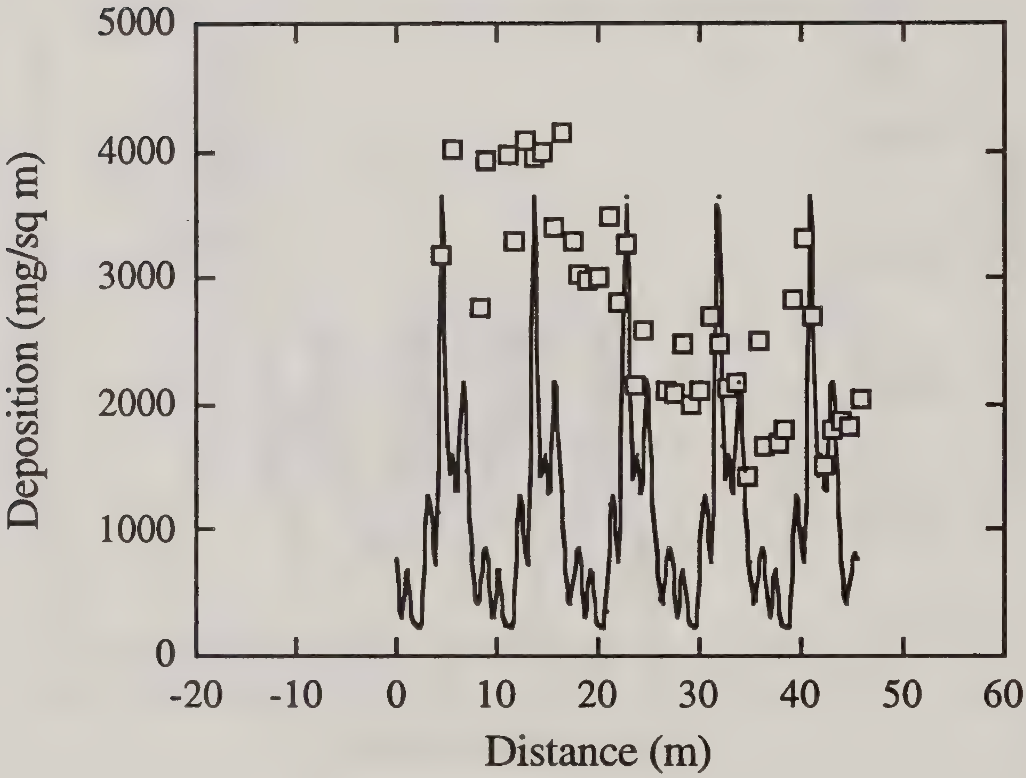



Figure 14: Trial 11 observed and predicted mass deposited on the ground, release height = 1.5 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.40$.

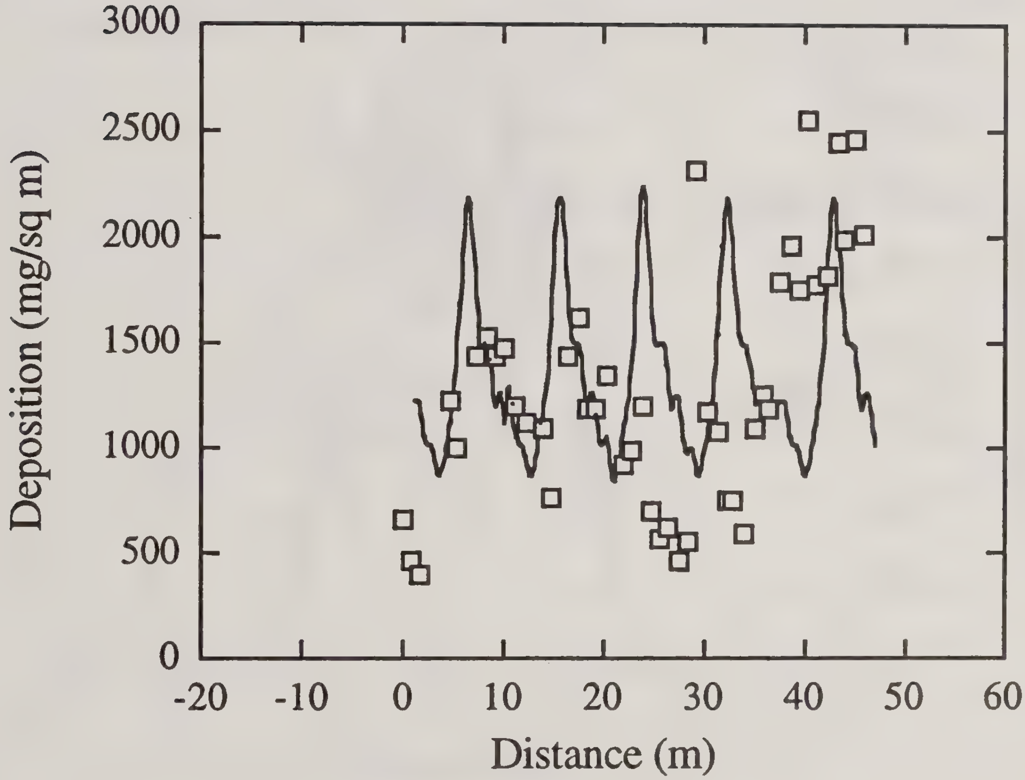



Figure 15: Trial 13 observed and predicted mass deposited on the ground, release height = 1.5 meters above mean canopy height. Observed data are shown as open squares, FSCBG prediction is shown as a solid line. Horizontal position 0 meters is at tree row 10, positive pointing east. Correlation to mass, $R^2 = 0.48$.

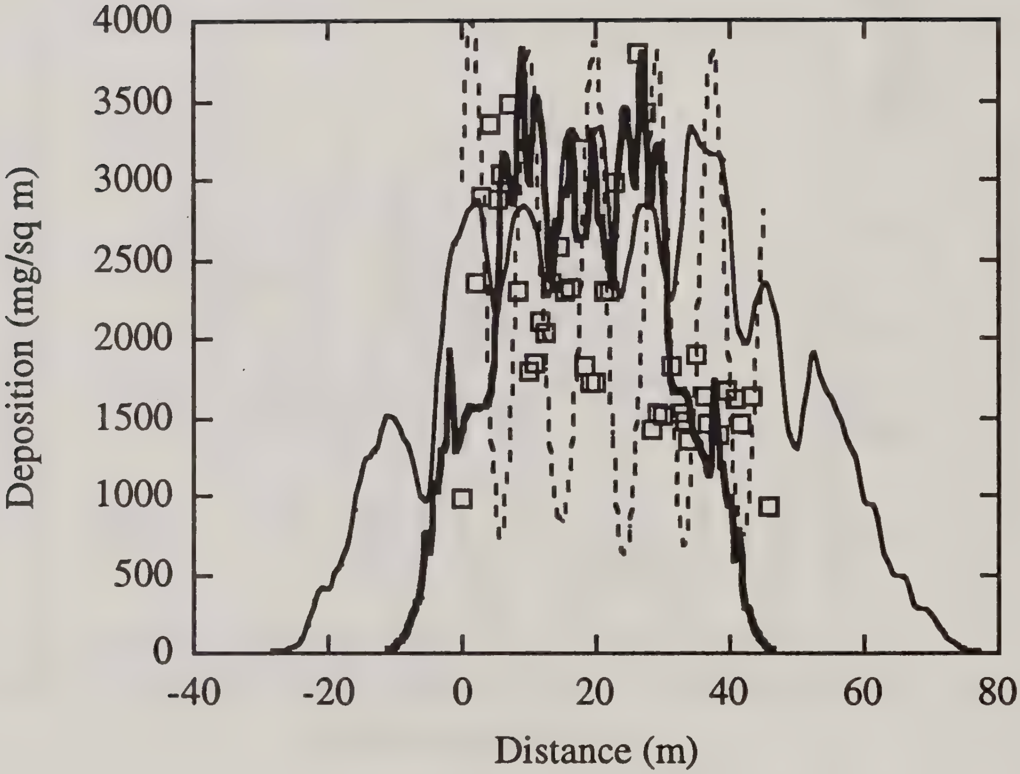



Figure 16: Trial 2, observed and predicted mass deposited on the ground, release height = 6.1 m above mean canopy height: observed data are shown as open squares, FSCBG predictions are shown as a bold line, AGDISP predictions from Teske (1989) are shown as a solid line, and CBG predictions from Rafferty et al. (1982) are shown as a dashed line.

Table 11: Predicted and Observed Mass and Number Median Diameter in Open Terrain for the Withlacoochee Trials

| | Mass Median Diameter (micrometers) | | Number Median Diameter (micrometers) | |
|---|---|---|---|---|
| Trial | Predicted | Observed | Predicted | Observed |
| 2 | 325 | 405 | 166 | 113 |
| 3 | 318 | 352 | 152 | 142 |
| 5 | 342 | 475 | 202 | 177 |
| 6 | 589 | 572 | 308 | 165 |
| 7 | 575 | 572 | 274 | 207 |
| 10 | 311 | 525 | 135 | 175 |
| 11 | 349 | 595 | 118 | 146 |
| 13 | 324 | 482 | 137 | 159 |

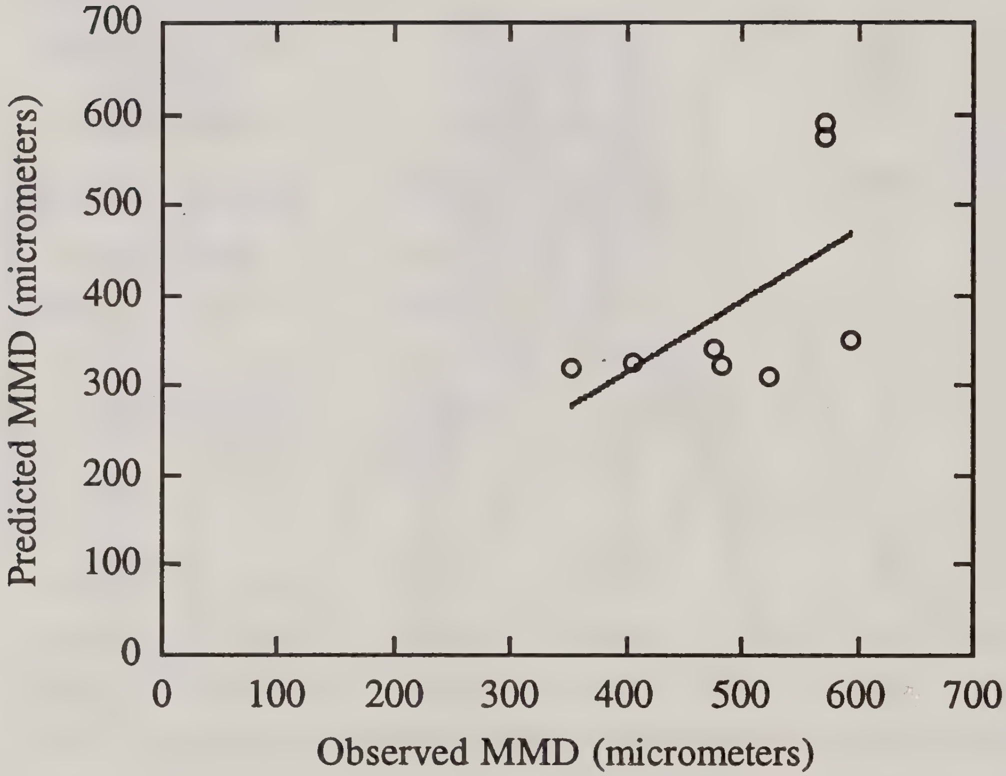



Figure 17: Observed and predicted mass median diameter (MMD) for Withlacoochee trials 2, 3, 5, 6, 7, 10, 11, and 13. Least squares slope through the points = 0.79

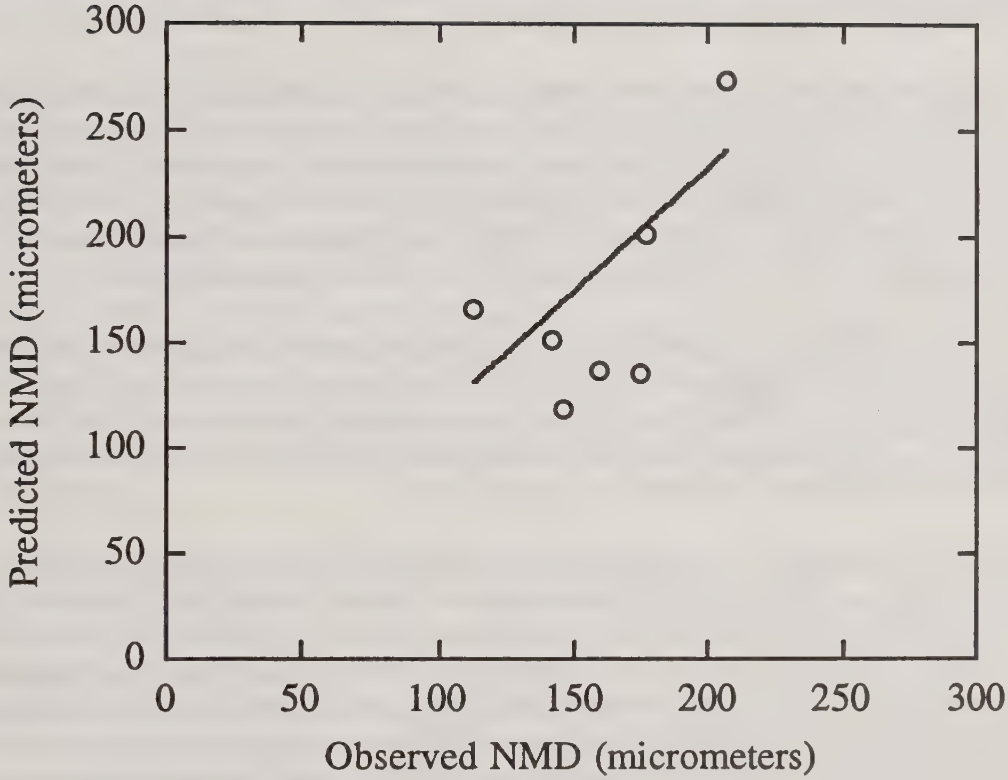



Figure 18: Observed and predicted number median diameter (NMD) for Withlacoochee trials 2, 3, 5, 6, 7, 10, 11, and 13. Least squares slope through the points = 1.16

## 4. FSCBG Simulation of Canopy Deposition Data

To model the canopy deposition data available from the field trials, discrete receptors were placed in each type of pine canopy as indicated by the canopy lines shown in Figure 2. FSCBG predictions for top-of-can deposition in the slash pine canopy correspond to field test data from canopy lines 1-2 and 3-4. Predictions for top-of-can deposition in the Ocala sand pine canopy correspond to data from canopy lines 9-10 and 11-12. Deposition along the canopy lines was simulated at the same time as ground deposition, using the same canopy modeling and aircraft, meteorological, and spray system data as was presented in the previous section.

Deposition levels predicted in this manner are compared with the field test data from Barry et al. (1982) in Table 12. Because of the great amount of scatter in the field test data, discussed in Section 2.5, only average deposition along canopy lines is addressed here. Thus, Table 12 shows the average drop deposition along canopy lines in each pine orchard during each trial. For trial 6, data were only recorded for canopy lines 1-2 and 3-4 (in the slash pine orchard). No canopy data at all were available for trial 7.

A scatterplot of the predicted and observed average drop deposition along the canopy lines for each trial is shown in Figure 19. Average data and predictions from both orchards are shown on the same plot. A least squares line through these points gives a slope of 0.87, indicating very good correlation of predicted average drop deposition to observed average deposition along the canopy lines.

Deposition in the tree crowns was recovered from Mylar covered can samplers in trials 5, 7 and 10. The cans were positioned as shown previously in Figure 3. The mean recovery of Manganese Sulfate (in micrograms) from the Mylar samplers at different levels in the canopy is given by Barry et al. (1982). A significant amount of the Manganese Sulfate tracer was unaccounted for as spray passed through the canopy; the levels of tracer measured at each crown height were very small. Barry et al. (1982) attribute the high percent loss of spray indicated by this finding to decreasing air velocities, collection efficiencies, and scavenging effect of the foliage.

Deposition data in the tree crowns were also recovered from Kromekote cards placed on top of can samplers in trials 3, 5, 6, 10, 11 and 13. The cans were again positioned as shown in Figure 3 (Kromekote can samplers in trial 5 were placed adjacent to the Mylar cans). Table 13 shows the mean drop and volume deposition (in drops per square centimeter and gallons per acre, respectively) recovered from Kromekote samplers at each tree height, including the canopy top (these data are the average drop and volume deposition observed on canopy lines for each trial). The corresponding mean predicted drop and volume deposition levels at these crown elevations are also shown.

Additional foliage deposition data are available for trial 3: Table 14 shows the mean drop deposition per square centimeter of needle area at three crown heights, with the corresponding mean drop deposition data for trial 3 (presented in Table 13). Foliage data are given by tree type, and then averaged. Data from the tops of beverage can samplers (presented for all the trials in Table 13) are only available as averages for the entire test area.

Looking first at the observed levels of deposition within the tree crown, it is immediately clear that deposition recovered from the Kromekote samplers (and from the foliage) follows the same pattern as that observed with the Mylar samplers, discussed above: a significant amount of spray is captured by the canopy, and most of it is captured at the top of the crown. Comparatively little spray appears to pass through to the lower crown and then to the ground; in other words, much of the spray is lost to the canopy. This finding is consistent with previous studies of coniferous canopies (Barry et al., 1981, and Barry, 1984). It is also interesting to note that, for the top-of-can samplers, average levels of drop deposition observed at the top of the tree crowns are much higher than those observed along the canopy line. The tree crown samplers were all within tree driplines (as shown in Figure 3), whereas the canopy line was strung between trees.

The mean foliage data (presented in Table 14) indicate lower levels of drop deposition at each crown height than the top-of-can sampler data; however, drop deposition measured by the top-of-can samplers was very similar to drop deposition measured on the slash pine needles. The collection efficiencies of the two types of pine canopies are obviously very different: despite the apparent scatter in the data shown in Table 8, the slash pine needles clearly collected at least three times as many drops as the Ocala pine needles. Several studies of pesticide deposition on coniferous foliage have concluded that the majority of spray droplets (over 80%) which are deposited on needles are less than 60 micrometers in diameter (Barry et al., 1977; Barry and Ekblad, 1978; and Barry, 1984). These small particles are particularly susceptible to turbulence within the canopy, and are apparently being efficiently collected by the dense coniferous foliage in the slash pine canopy.

While FSCBG predicts the drop and volume deposition at the canopy line very well (as evidenced by Figure 19), average drop deposition levels observed at each crown elevation are quite different from predicted levels. FSCBG underpredicts the level of drop deposition throughout the tree crown (in most cases by at least half). This could be due in part to the non-uniformity of the canopy (and of tree dimensions), in part to differences between the actual and available drop size distributions, and in part to the factors affecting small droplet transport through the canopy, discussed above. Moreover, Barry et al. (1977) note that a majority of the spray particles observed on Douglas-fir needles sprayed with a mexacarbate insecticide formulation were found on the underside of the needles. FSCBG modeling of the transport of spray through the canopy can not account for deposition on the underside of a surface.

Despite the differences apparent in Table 13, scatterplots of the average predicted and observed drop and volume deposition yield encouraging results (Figures 20 and 21). Least squares lines through the points give slopes of 0.49 for drop deposition and 0.61 for volume deposition. These results are encouraging because the typical canopy profile used in the model and the actual canopy profile experienced by the falling spray may be quite different.

Table 12: Predicted and Observed Average Drop Deposition in the Orchard Canopy by Tree Type for the Withlacoochee Trials

| | Average Drop Deposition (drops/sq cm) | | | |
|---|---|---|---|---|
| | Slash pine | | Ocala sand pine | |
| Trial | Predicted | Observed | Predicted | Observed |
| 2 | 63 | 94 | 57 | 66 |
| 3 | 65 | 70 | 58 | 59 |
| 5 | 52 | 63 | 49 | 57 |
| 6 | 18 | 25 | -- | -- |
| 10 | 69 | 79 | 46 | 53 |
| 11 | 71 | 82 | 53 | 60 |
| 13 | 51 | 65 | 49 | 63 |

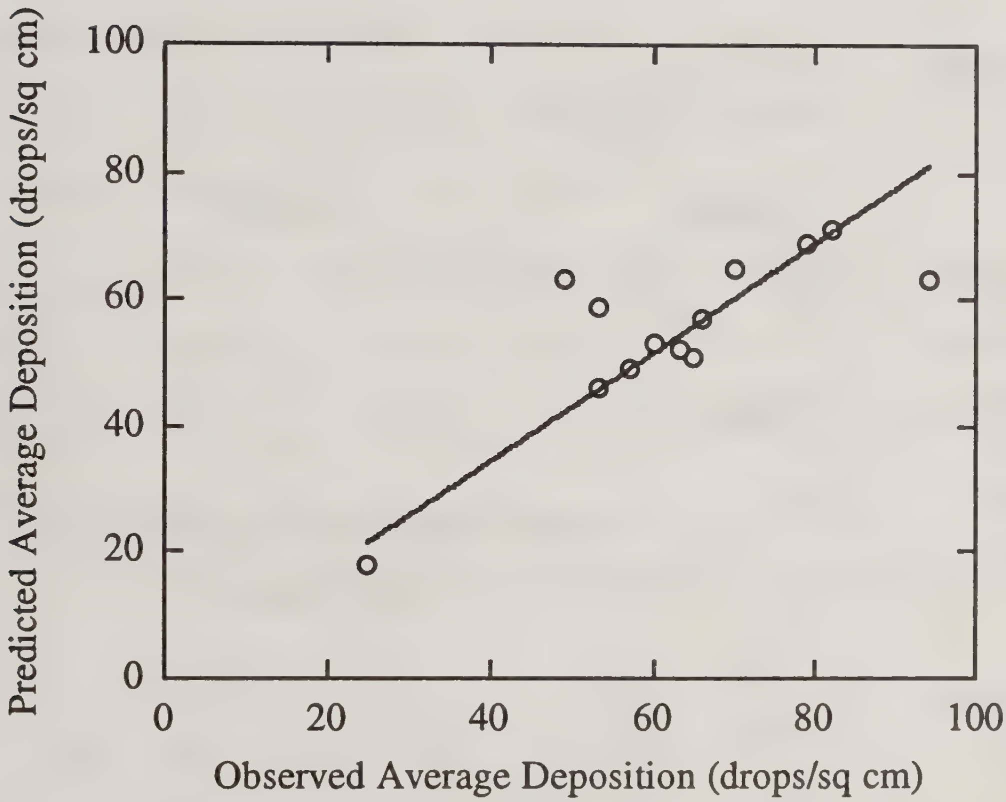



Figure 19: Observed and predicted average drop deposition along canopy lines for Withlacoochee trials 2, 3, 5, 6, 7, 10, 11, and 13. Data from both orchards (slash and Ocala sand pine) are shown. Least squares slope through the points = 0.87.

Table 13: Predicted and Observed Average Drop Deposition in the Tree Crowns

| Sampling Location | Average Drop Deposition (drops per square centimeter) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial Number | | | | | | | | | | | |
| | 3 | | 5 | | 6 | | 10 | | 11 | | 13 | |
| | P[1] | O[2] | P | O | P | O | P | O | P | O | P | O |
| Canopy | 62 | 65 | 50 | 60 | 18 | 25 | 58 | 66 | 62 | 71 | 50 | 64 |
| Tree: Upper Crown | 64 | 119 | 60 | 136 | 18 | 80 | 56 | 121 | 61 | 156 | 50 | 115 |
| Middle Crown | 55 | 106 | 51 | 107 | 15 | 60 | 49 | 93 | 53 | 145 | 42 | 102 |
| Lower Crown | 48 | 89 | 42 | 57 | 13 | 32 | 42 | 78 | 46 | 124 | 39 | 79 |

| Sampling Location | Average Volume Deposition (gallons per acre) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial Number | | | | | | | | | | | |
| | 3 | | 5 | | 6 | | 10 | | 11 | | 13 | |
| | P | O | P | O | P | O | P | O | P | O | P | O |
| Canopy | 5.0 | 5.7 | 6.5 | 15.5 | 4.0 | 3.5 | 10.0 | 16.0 | 16.0 | 17.9 | 6.4 | 8.8 |
| Tree: Upper Crown | 4.5 | 6.1 | 6.2 | 19.6 | 3.9 | 5.3 | 10.0 | 23.5 | 15.9 | 18.3 | 6.4 | 14.1 |
| Middle Crown | 2.8 | 4.4 | 3.6 | 12.6 | 2.9 | 7.1 | 8.9 | 16.2 | 14.8 | 17.4 | 5.2 | 10.4 |
| Lower Crown | 2.0 | 4.3 | 3.2 | 5.0 | 2.5 | 4.8 | 7.2 | 11.0 | 12.0 | 10.7 | 4.2 | 5.0 |

1. Predicted: average predicted deposition for all samplers at this crown/canopy location.

2. Observed: average observed deposition for all samplers at this crown/canopy location.

Table 14: Predicted and Observed Drop Deposition in the Tree Crowns, Trial 3

| | Average Drop Deposition (drops/sq cm) | | | | |
|---|---|---|---|---|---|
| | Predicted | Observed | | | |
| Sampling Location | | Slash Foliage | Ocala Foliage | Mean Foliage | Mean Can Sampler |
| Upper Crown | 64 | 112 | 13 | 62 | 119 |
| Middle Crown | 55 | 108 | 13 | 60 | 106 |
| Lower Crown | 48 | 71 | 8 | 40 | 89 |

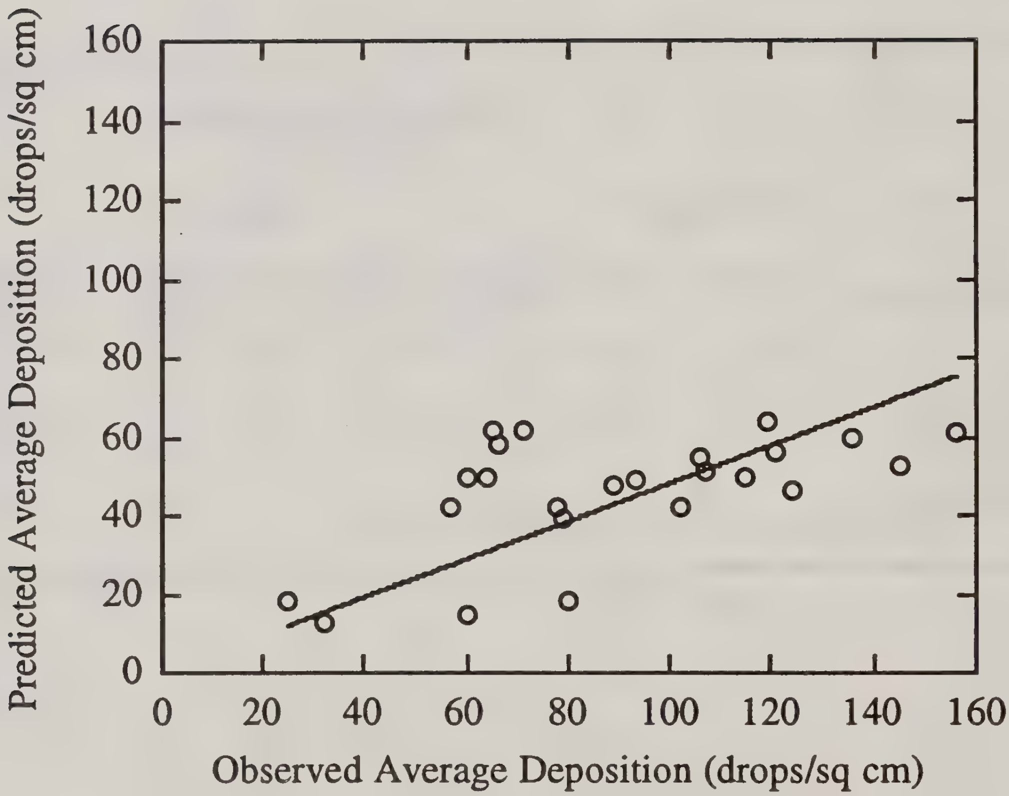



Figure 20: Observed and predicted average drop deposition in sample tree crowns for Withlacoochee trials 3, 5, 6, 10, 11, and 13. Data from three crown elevations and the canopy lines are shown. Least squares slope through the points = 0.49.

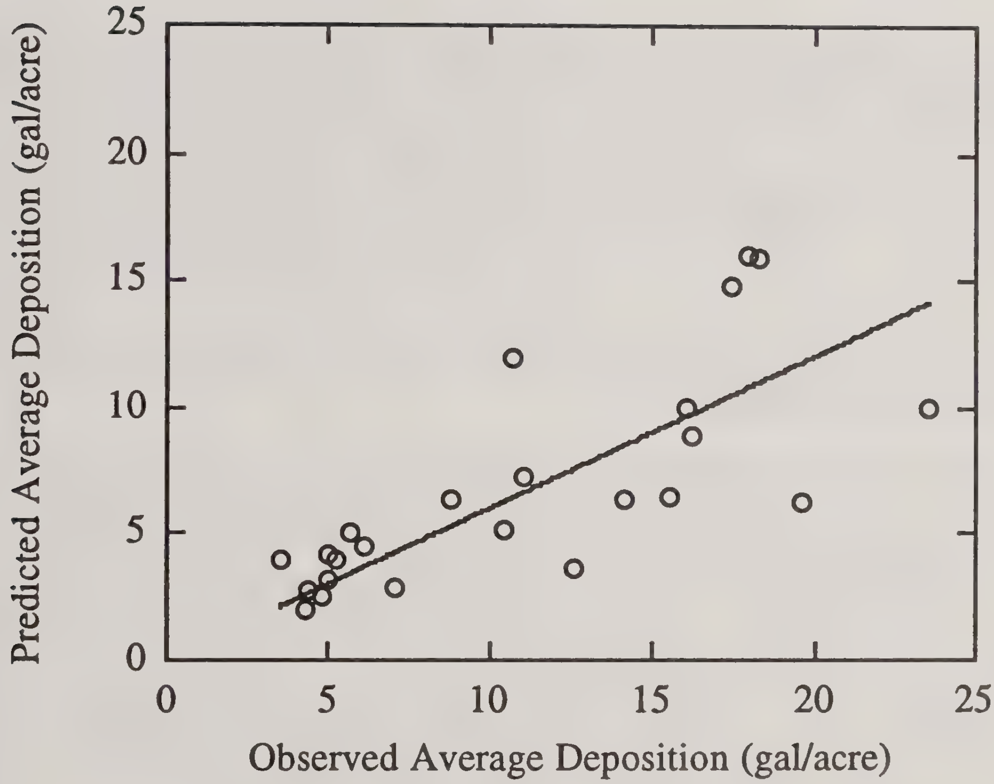



Figure 21: Observed and predicted average volume deposition in sample tree crowns for Withlacoochee trials 3, 5, 6, 10, 11, and 13. Data from three crown elevations and the canopy lines are shown. Least squares slope through the points = 0.61.

# 5. FSCBG Simulation of Downwind Drift

On February 20, two drift studies were conducted with the Hughes 500C helicopter. The first study was conducted during trials 11 through 14: can and card samplers were placed as shown in Figure 4 (and previously described in Section 2 of this report), just outside the orchard perimeter. Drop deposition data (in drops per square centimeter) were recorded for Kromekote cards placed on the ground as well as for the tops of Kromekote-wrapped cans.

Data recorded for trials 11 and 13 are shown in Figures 22 and 23. Note that these data were recorded from samplers 55 through 82, along a line parallel to the aircraft flight lines and just beyond the canopy edge. Therefore, all data shown for these two trials are at the same distance away from the last spray line. Barry et al. (1982) state that the pilot's on-off points were within 18 meters of the canopy edge at the north and south ends of the orchard, but does not give an exact position for the on/off points in each trial. Aircraft position for the first swaths flown in trials 11 and 13 was the same: between tree rows 2 and 3 (Table 2). The drift data shown are thus along a line which is 32.0 meters away from the spray block, in the open. Since all data for each trial are the same distance away from the spray block, average drop deposition values (as indicated in Figures 19 and 20) are used for comparison to FSCBG.

There is quite a lot of scatter in the drop deposition data recorded, as can be seen in the figures. The average deposition at 32 meters downwind, trial 11, is 6.9 drops per square centimeter for the ground cards and 7.6 drops per square centimeter for the cans. The average deposition at 32 meters downwind, trial 13, is 2.6 drops per square centimeter for the ground cards and 2.3 drops per square centimeter for the cans. Thus, despite the scatter in the observed data, the average drop deposition observed in both trials at this location downwind is nearly the same for the cans (which were placed on 1.5 meter poles) as for the ground cards. Although both trials show minimal drop deposition at 32 meters downwind of the spray block compared to average observed deposition in the canopy (given in Table 12), there was apparently slightly more drift during trial 11. This indicates that, although the canopy appears to have captured most of the spray material, the on-off location did not occur at the edge of the canopy. In any case, there is minimal drift at 30 meters from the spray block. This finding is consistent with a previous drift study conducted with a helicopter equipped with a nozzle spray system and reported by MacNichol (1996).

Technically, FSCBG can not handle a change from canopy to open area; however, a stand alone calculation may be made with the dispersion model from the FSCBG Gaussian equations (Teske et al., 1993b). These results depend on the meteorological conditions for each of the trials (Table 4), and are shown from the canopy edge to 80 meters downwind by the solid curves in Figures 22 and 23. Average field test drop deposition data are also shown in the figures.

The second drift study conducted on February 20 consisted of six special trials, designated D1 through D6, over an open area of the orchard. Kromekote card samplers were placed on the ground as shown in Figure 5. These trials were intended to assess the difference in drift potential between a water base spray with and without Nalco-trol;

however, the limited trials and data did not support such analysis (Barry et al., 1982). Nevertheless, both drop and volume deposition data were recorded for the six special trials, in drops per square centimeter and ounces per acre, respectively.

Meteorological data were also recorded for these six trials, and are given in Table 15. These data are assumed to have been recorded at the same heights as previously specified in Table 4. Note that exact wind direction and speed are not given. Relative humidity is assumed to be the same as that recorded for trial 11 (also conducted on February 20).

For these six trials, the Hughes 500C helicopter applied a tank mix of dyed water at 5.0 gallons per acre. As mentioned above, no distinction will be made between trials conducted with Nalco-trol and trials conducted without. The drop size distribution used for these trials is the same as that used for trials 10, 11 and 13 (Table 10). The release height for trials D1 through D6 was 7.6 meters, and aircraft flight speed was 11.2 m/s. The aircraft position is stated as normal to wind direction: trials D2 through D6 were therefore flown with approximately a 90 degree crosswind, and trial D1 was flown with approximately a 45 degree crosswind (Table 15).

FSCBG simulations of ground deposition for trials D1 through D6 are compared to the field test deposition data in Figures 24 through 29. FSCBG predicts drop deposition levels well for all six trials, particularly at distances greater than 40 meters downwind. It should be noted that exact wind direction and speed were not given for each trial, and the drop size distribution being used for the helicopter spray system is not exactly representative of the actual distribution sprayed. Trials D2 through D6 differ mainly in wind speed; both the observed and predicted deposition data show that higher crosswinds flatten the deposition pattern, but cause significant amounts of the spray to continue to drift over the measured distance downwind (Figures 26 and 28). However, the small amount of wind in trial D4 (Figure 27) still caused significant drift downwind of the peak deposition. In their assessment of the observed drift deposition data, Barry et al. (1982) also noted this finding: they suggest that, although conventional wisdom indicates that winds would favor drift, the unstable afternoon air mixes, deposits, diffuses, and dilutes the cloud.

Although the volume deposition level for trial D1 is predicted well, volume deposition levels for the other downwind drift trials are not predicted as well as drop deposition levels. For example, in trial D2 the drop deposition downwind of 40 meters is predicted very well, while the volume deposition is severely underpredicted. The observed levels of volume deposition may be overstated due to rain damage, noted by Barry et al. (1982) during the rest of the field trials and suggested by Barry (private communication, 1996) for this set of downwind drift data. Observed mass is determined from spread factors, which are not reliable when cards are damp: stains spread on damp cards, and the resulting mass calculation indicates greater mass deposition than is actually present.

One other set of drift data is presented in Barry et al. (1982). Prior to February 20, Mylar can samplers were placed on stakes, and Mylar horizontal samplers were positioned on the ground at the base of the stakes, at positions all around the orchard perimeter, as shown previously in Figure 4. These samplers were assessed for the presence of Manganese Sulfate salts (as described in Section 2.4), and Manganese Sulfate deposition

data are shown in Barry et al. (1982) for trials 5, 7 and 10. The highest recovery of Manganese Sulfate salts anywhere along the orchard perimeter during these three trials was 0.01245 gallons per acre, located approximately 18.3 meters south of the perimeter of the spray block. With the exception of one can sampler located 18.3 meters east of the spray block in trial 5, all other Manganese Sulfate drift deposition data recorded for trials 5, 7 and 10 were at least an order of magnitude smaller than the highest recovery. As indicated by Barry et al. (1982), the Manganese Sulfate drift data reveal very minimal drift along the orchard perimeter. These drift data are not simulated with FSCBG.

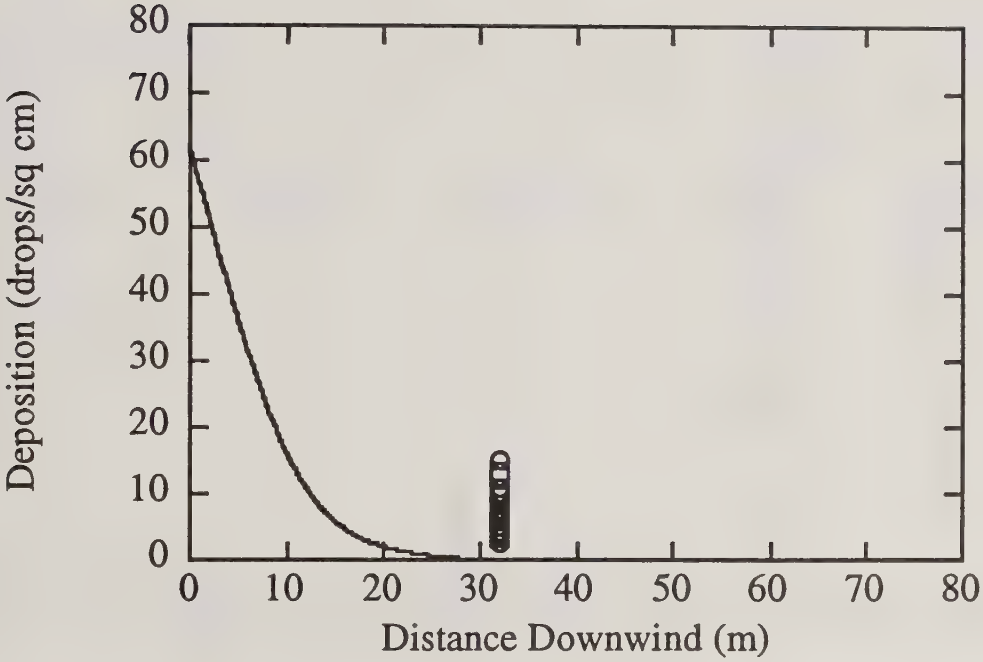



Figure 22: Observed downwind drop deposition for trial 11. Observed data on tops of Kromekote cans and on Kromekote ground cards are shown as open circles. FSCBG stand alone calculation is shown as a solid line. Average predicted deposition in the canopy for trial 11 = 62 drops/sq cm. Average observed deposition at 32 meters = 7.3 drops/sq cm.

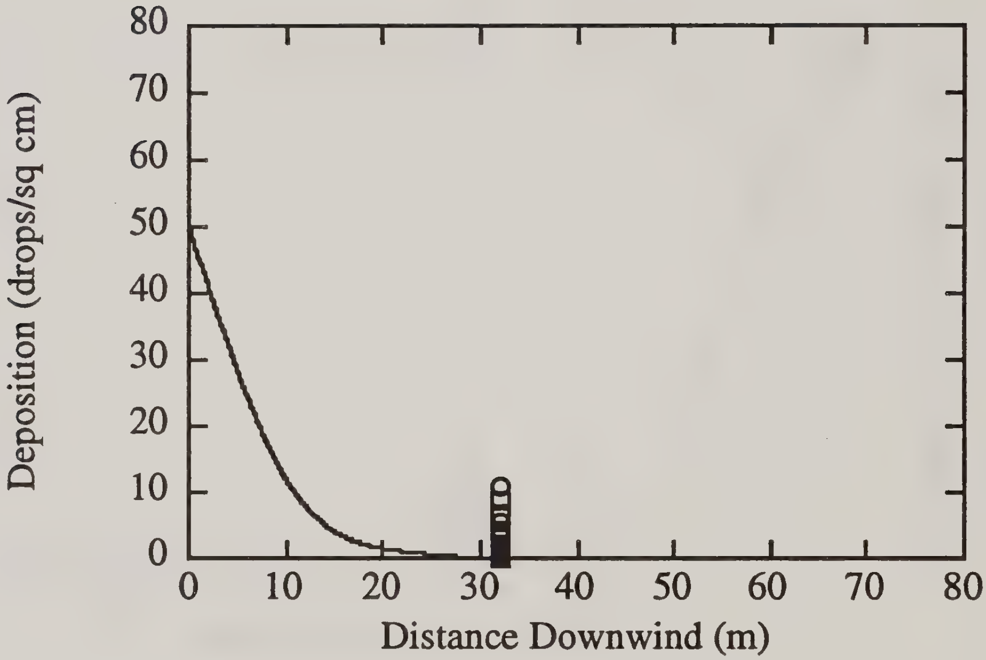



Figure 23: Observed downwind drift drop deposition for trial 13. Observed data on tops of Kromekote cans and on Kromekote ground cards are shown as open circles. FSCBG stand alone calculation is shown as a solid line. Average predicted deposition in the canopy for trial 13 = 50 drops/sq cm. Average observed deposition at 32 meters = 2.5 drops/sq cm.

Table 15: Meteorological Data Recorded For the February 20 Drift Trials

| | | | Wind | |
|---|---|---|---|---|
| Trial | Temperature (deg C) | Relative Humidity (%)[1] | Speed (m/s) | Direction |
| D1 | 20 | 61 | 2.7 | SSW |
| D2 | 20 | 61 | 3.1 | W |
| D3 | 20 | 61 | 4.5 | W |
| D4 | 20 | 61 | 1.5 | W |
| D5 | 18 | 61 | 7.1 | W |
| D6 | 17 | 61 | 3.6 | W |

1. Relative humidity was not recorded, but is assumed to be the same as for trial 13.

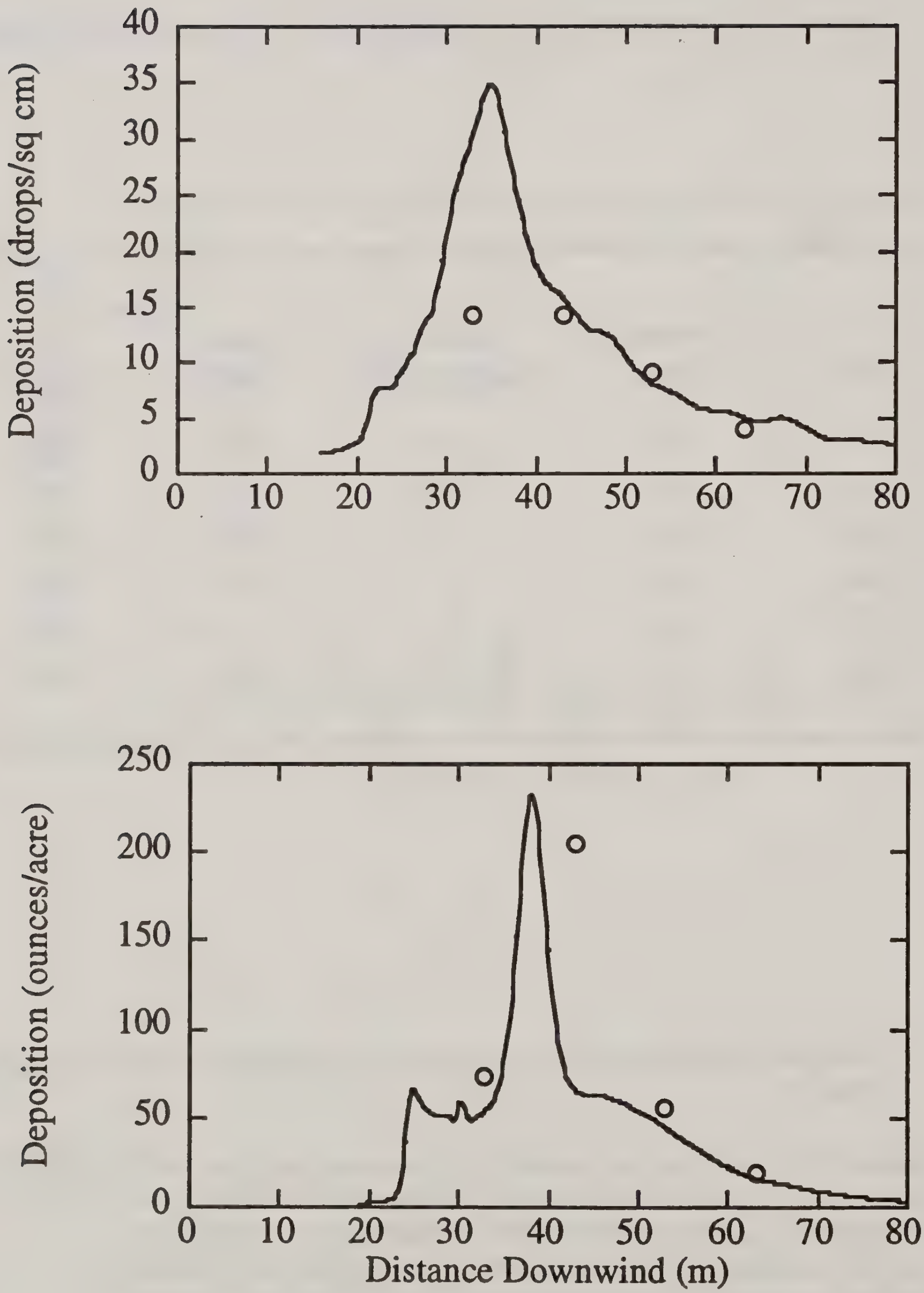



Figure 24: Observed and predicted downwind drift deposition (drops and volume) for the February 20 special drift study, trial D1. Observed data are open circles, FSCBG predictions are solid lines. Wind is from the southwest; distance is positive east.

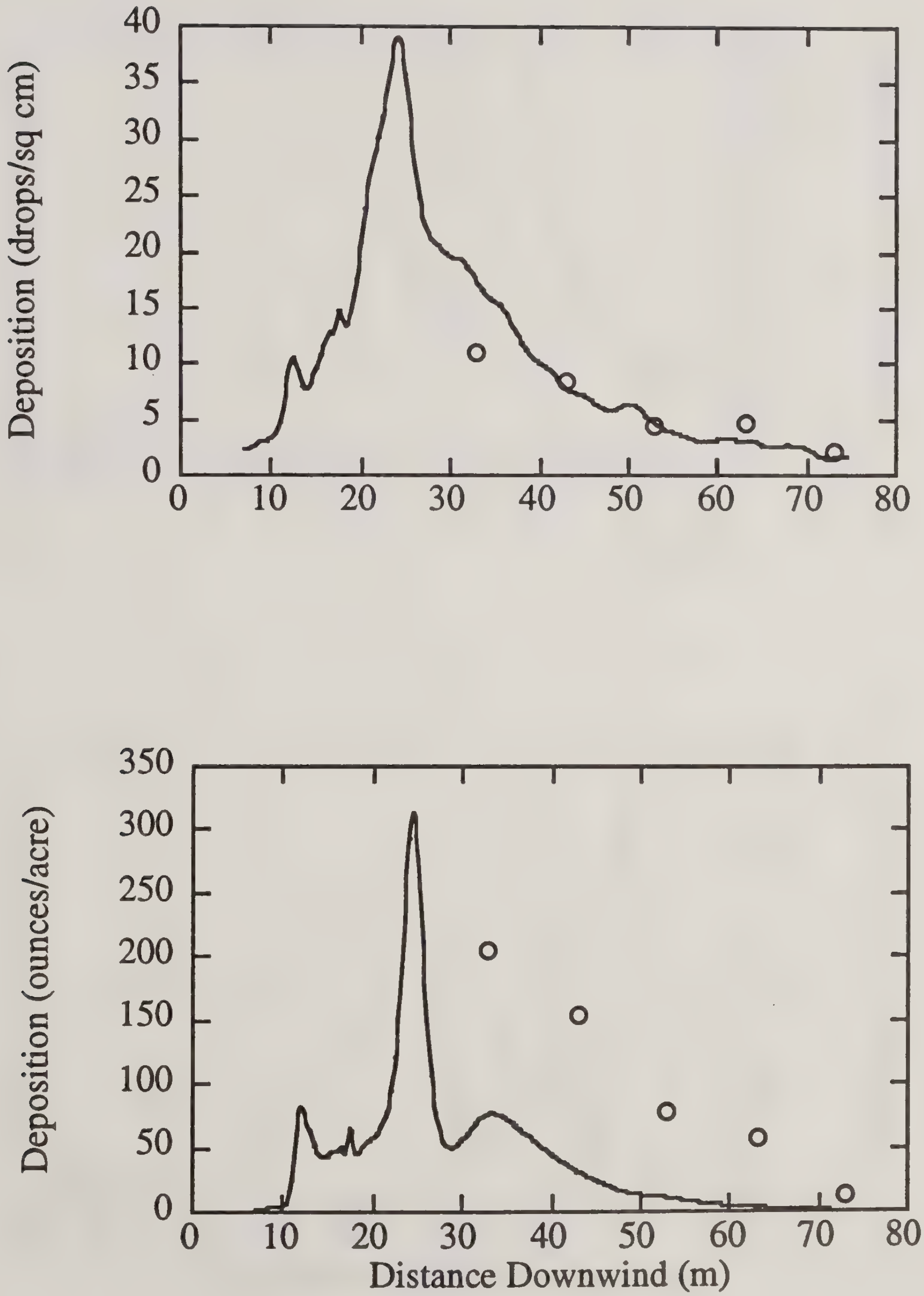



Figure 25: Observed and predicted downwind drift deposition (drops and volume) for the February 20 special drift study, trial D2. Observed data are open circles, FSCBG predictions are solid lines. Wind is coming from the west; distance is positive east.

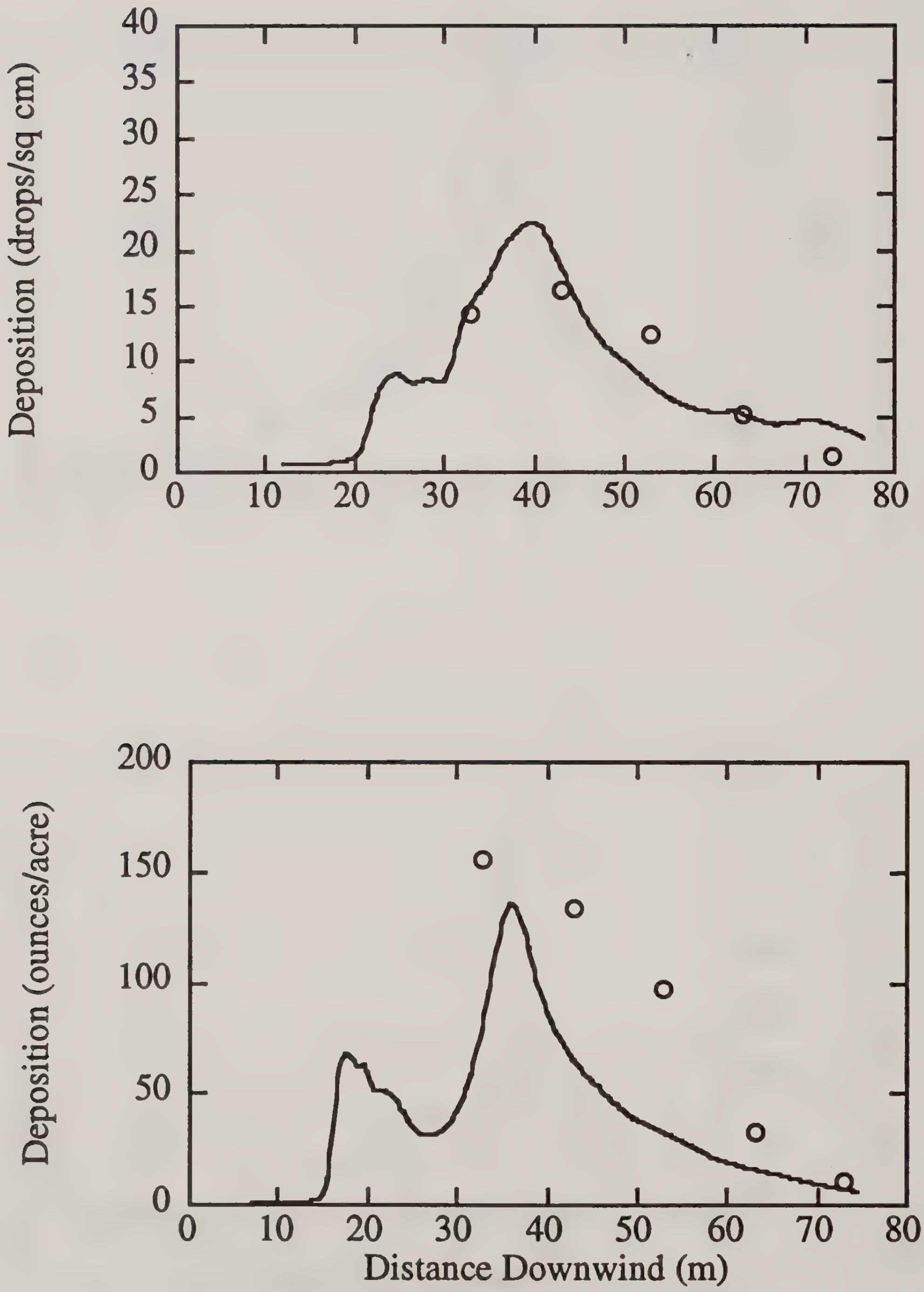



Figure 26: Observed and predicted downwind drift deposition (drops and volume) for the February 20 special drift study, trial D3. Observed data are open circles, FSCBG predictions are solid lines. Wind is coming from the west; distance is positive east.

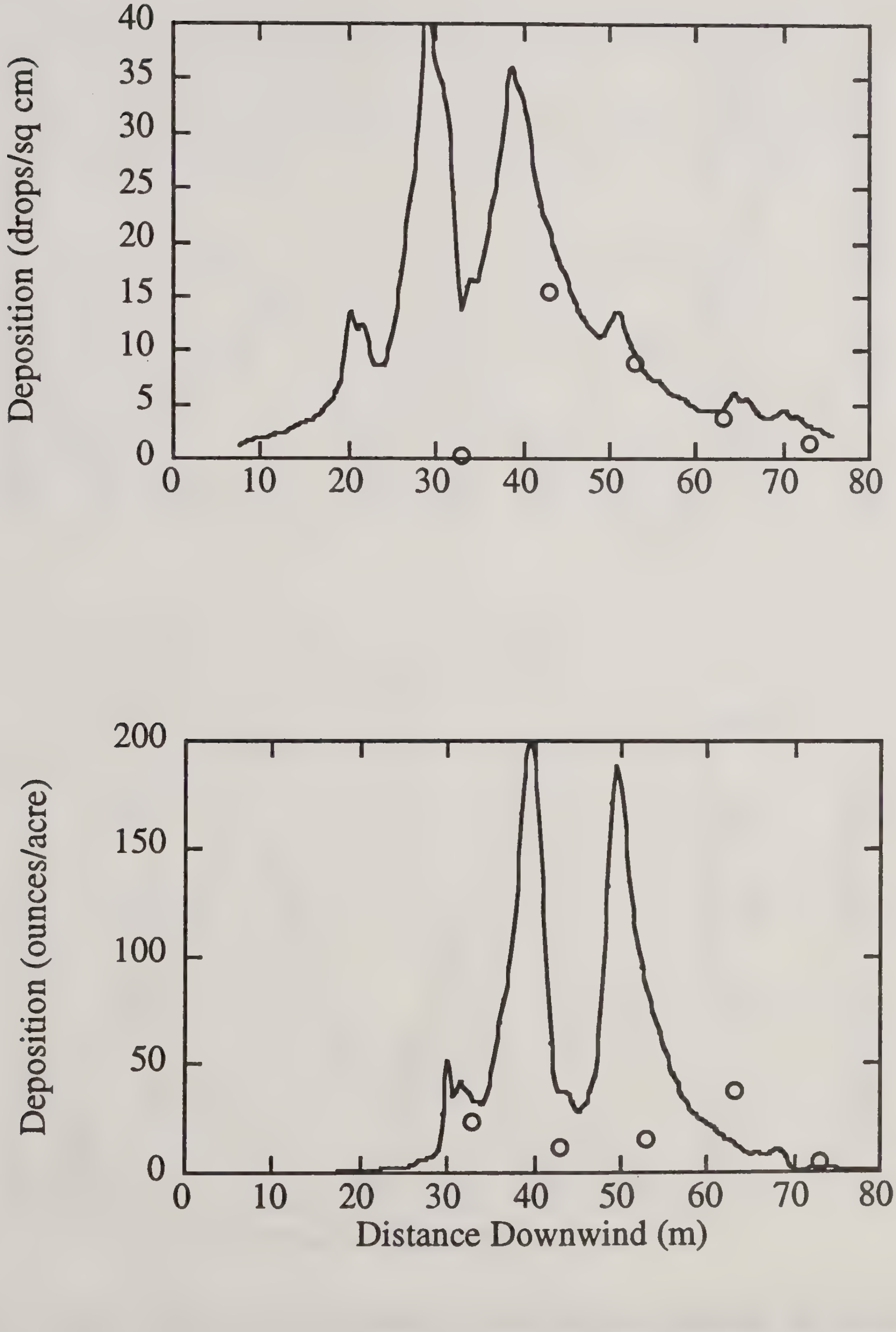



Figure 27: Observed and predicted downwind drift deposition (drops and volume) for the February 20 special drift study, trial D4. Observed data are open circles, FSCBG predictions are solid lines. Wind is coming from the west; distance is positive east.

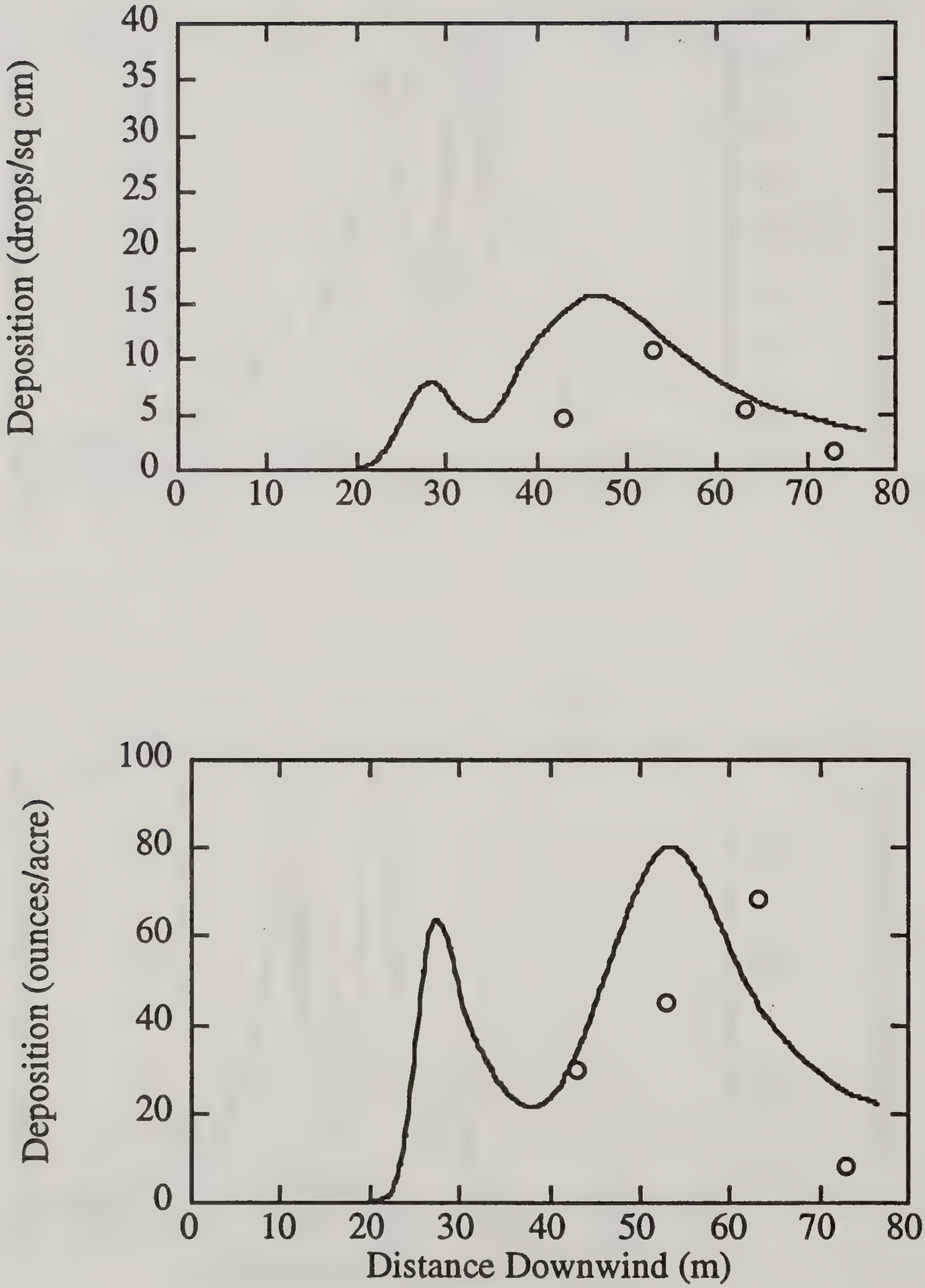



Figure 28: Observed and predicted downwind drift deposition (drops and volume) for the February 20 special drift study, trial D5. Observed data are open circles, FSCBG predictions are solid lines. Wind is coming from the west; distance is positive east.

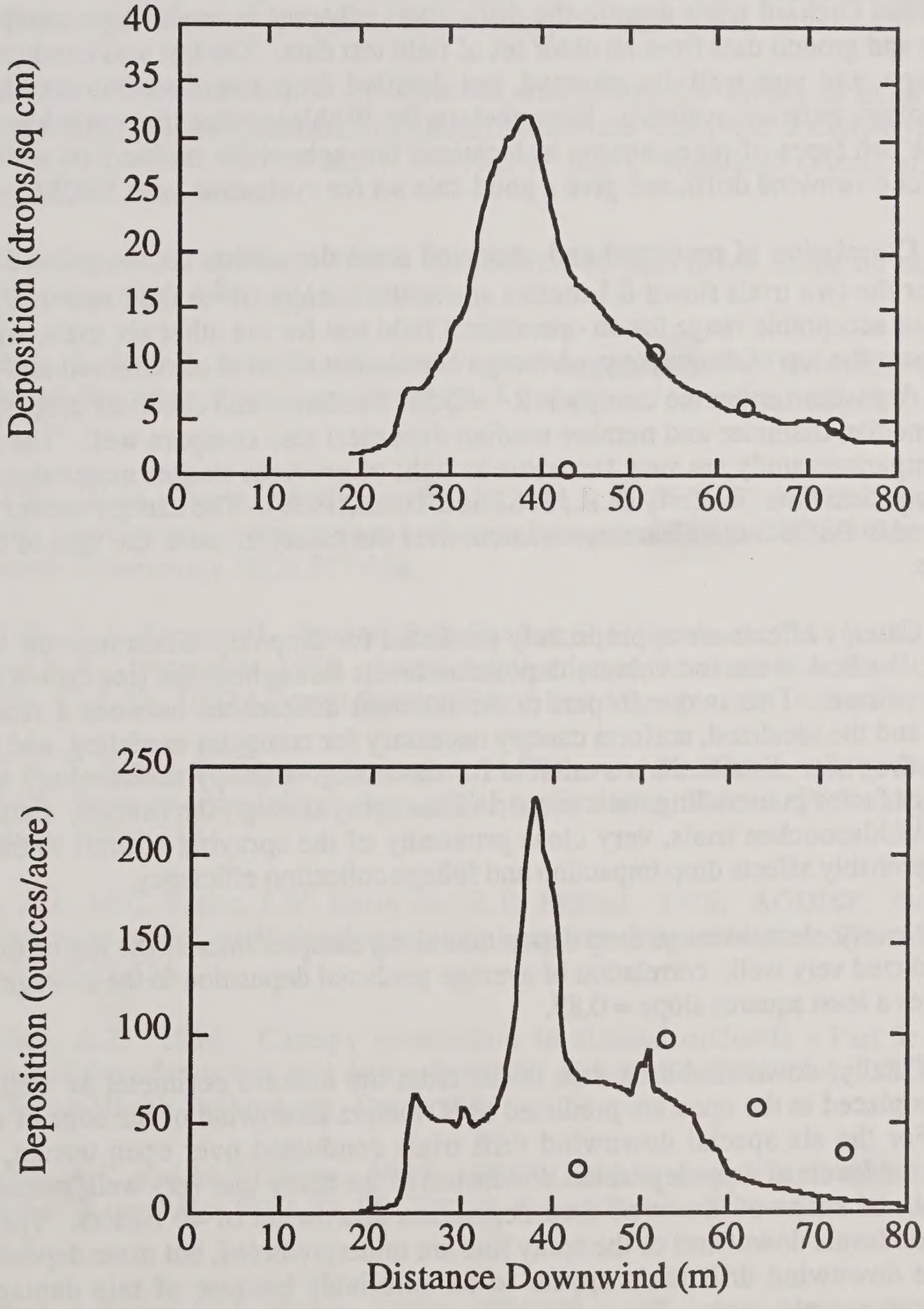



Figure 29: Observed and predicted downwind drift deposition (drops and volume) for the February 20 special drift study, trial D6. Observed data are open circles, FSCBG predictions are solid lines. Wind is coming from the west; distance is positive east.

# 6. Summary of Results

FSCBG gives good predictions of drop and mass deposition for the Withlacoochee State Seed Orchard trials despite the difficulties inherent in modeling a complex set of canopy and ground data from an older set of field test data. The test was conducted fifteen years ago, and was well-documented, but detailed drop size distributions and canopy meteorology were not available. Nevertheless, the Withlacoochee trials provide deposition data for two types of pine canopy, in locations throughout the orchard, as well as in the open (for downwind drift), and give a good data set for evaluation with FSCBG.

Correlation of predicted and observed mass deposition on the ground was very good for the two trials flown 6.1 meters above the canopy ($R^2 = 0.81$ and 0.69) and was within an acceptable range for an operational field test for the other six trials, which were flown near the top of the canopy. Average correlation to mass of observed and predicted ground deposition under the canopy is $R^2 = 0.57$. Predicted and observed droplet size data (mass median diameter and number median diameter) also compare well. The results of this comparison study are very favorable in light of previous studies undertaken with the Withlacoochee data (Rafferty et al., 1982 and Teske, 1989). The canopy model currently employed in FSCBG is a clear improvement over the model in use at the time of the earlier analysis.

Canopy effects are appropriately predicted for drop deposition near the top of the canopy, but both mass and volume deposition levels throughout the tree crown are being underpredicted. This is due in part to the inherent differences between a real orchard canopy and the idealized, uniform canopy necessary for computer modeling, and in part to inexact drop size distributions available for modeling. Canopy meteorology is also an important factor in modeling the transport of the spray through the canopy. Furthermore, in the Withlacoochee trials, very close proximity of the spraying aircraft to the canopy foliage probably affects drop impaction and foliage collection efficiency.

Nevertheless, average drop deposition along sampler lines at the top of the canopy was predicted very well; correlation of average predicted deposition to the average field test data gives a least squares slope = 0.87.

Finally, downwind drift data levels from the orchard perimeter as well as from samplers placed in the open are predicted to 80 meters downwind of the edge of the spray lines. For the six special downwind drift trials conducted over open terrain, FSCBG predicts the levels of drop deposition downwind of the spray line very well, matching both the level and shape of observed drop deposition downwind of 40 meters. The volume deposition levels downwind of the spray line are underpredicted, but mass deposition data from the downwind drift trials appear to be unreliable because of rain damage to the Kromekote sample cards. Thus, the mass observed during some of the drift trials is probably overstated.

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